Physics 315: Galaxies & the ISM

- Class meets T TH 8:30 – 9:45
- Office hours 9:45 – 10:45 T Th
- Office Physics 202
- Class web site:

http://lheawww.gsfc.nasa.gov/users/ddavis/courses/phy315.html

Course Work

- Midterm exam (30%)
- Final exam (40%)
- Homework (20%)
- Project (10%)

Homework #1: 1.2 1.3,1.4, 2.1, 2.4

Course Work cont.

- Textbook

  Galaxies in the Universe

  Sparke & Gallagher 2nd edition

  - Make sure you check the errata

    www.astro.wisc.edu/~sparke/book/errata

Homework #1: 1.2 1.3,1.4, 2.1, 2.4

Goals for this course

- Basic nature of galaxies
- What type of galaxy do we live in?
- Different galaxy types
- What does our Galaxy live in?
- Large scale structure
- X-ray properties
- “odd” galaxies

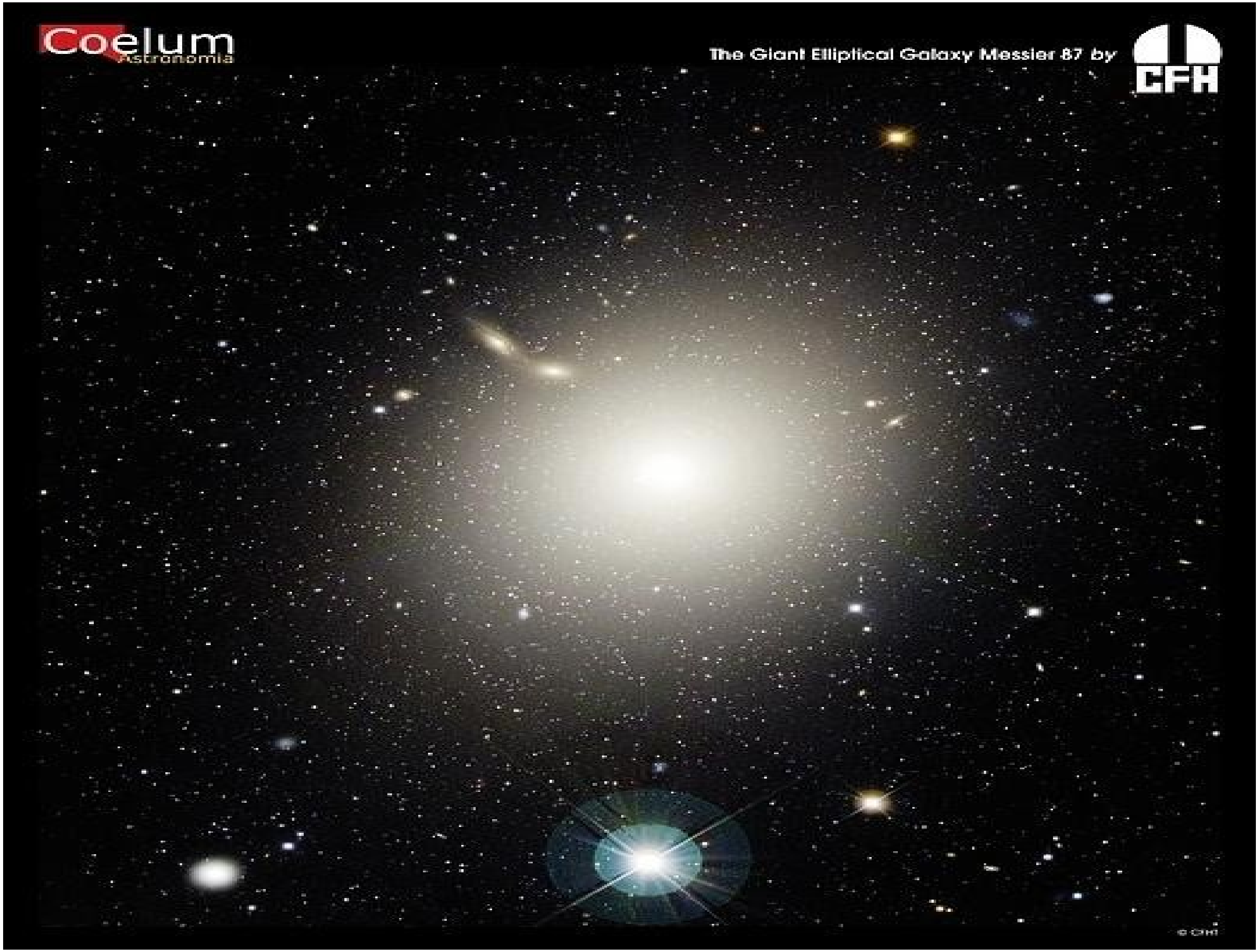
Galaxies

- “Island Universes”
  - Large collections of stars
  - Bound by self gravity
  - Have a variety of shapes
    - Spiral
    - Elliptical
    - Irregular

Spiral Galaxy

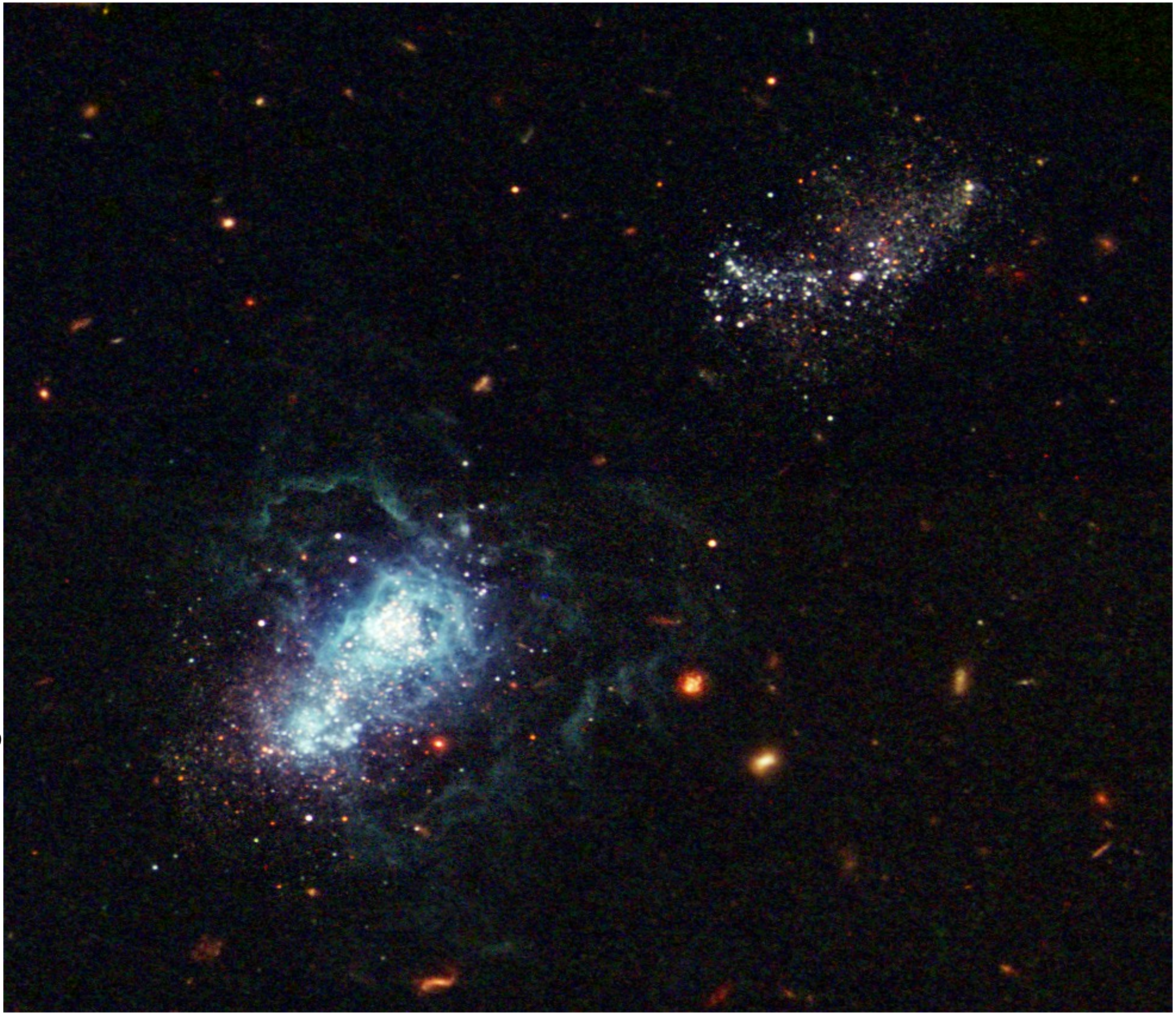
NGC 6946

Elliptical Galaxy



M87

Irregular Galaxy



Zwicky 18

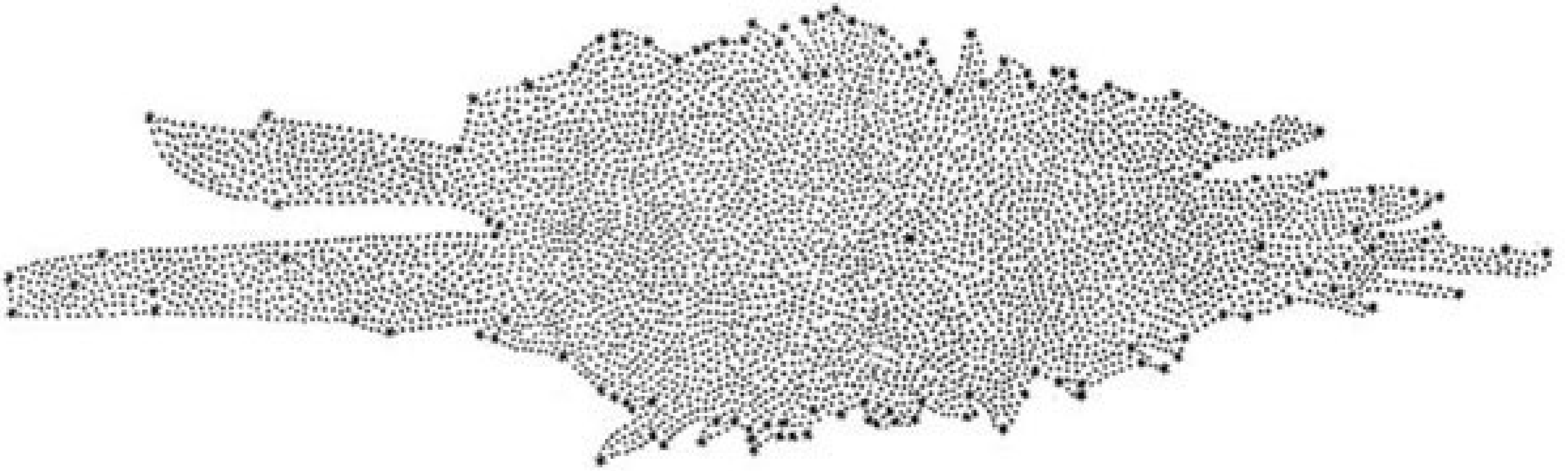
Galaxy Components cont.

In addition to the stars we have other components in the galaxies.

- Hot gas
- Cold gas
- Dust
- Black Holes
- Neutron Stars

Milky Way

Herschel's map of the Milky Way



Source: On the Construction of the Heavens.
By William Herschel, Esq. F. R. S.
Philosophical Transactions of the Royal Society of London, Vol. 75. (1785), pp. 213-266.

Kapteyn's Universe

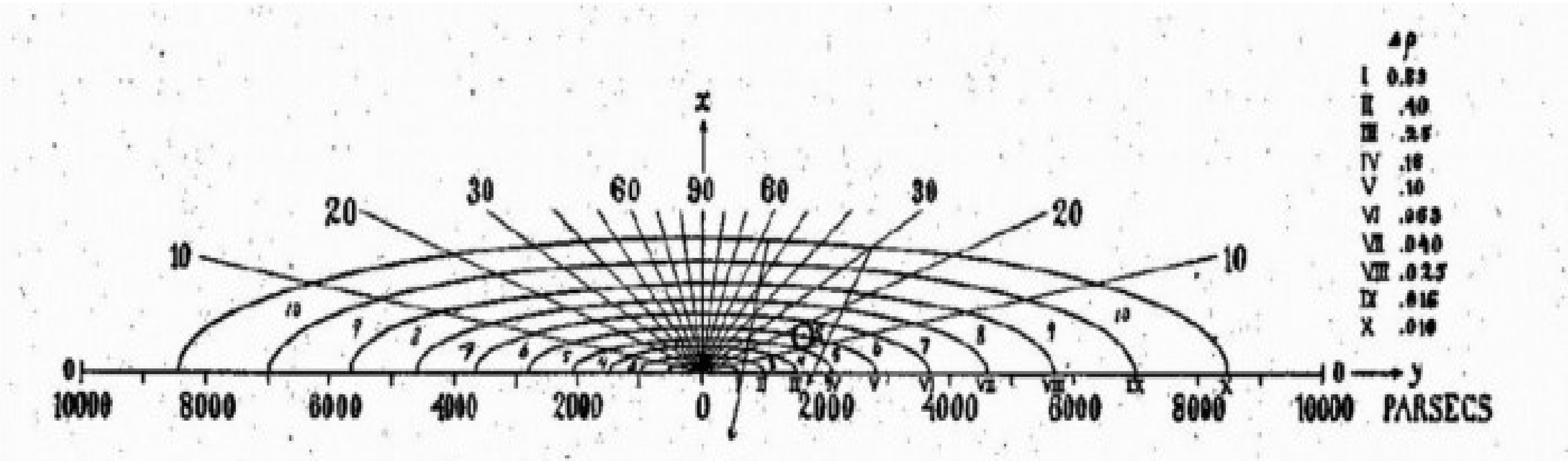
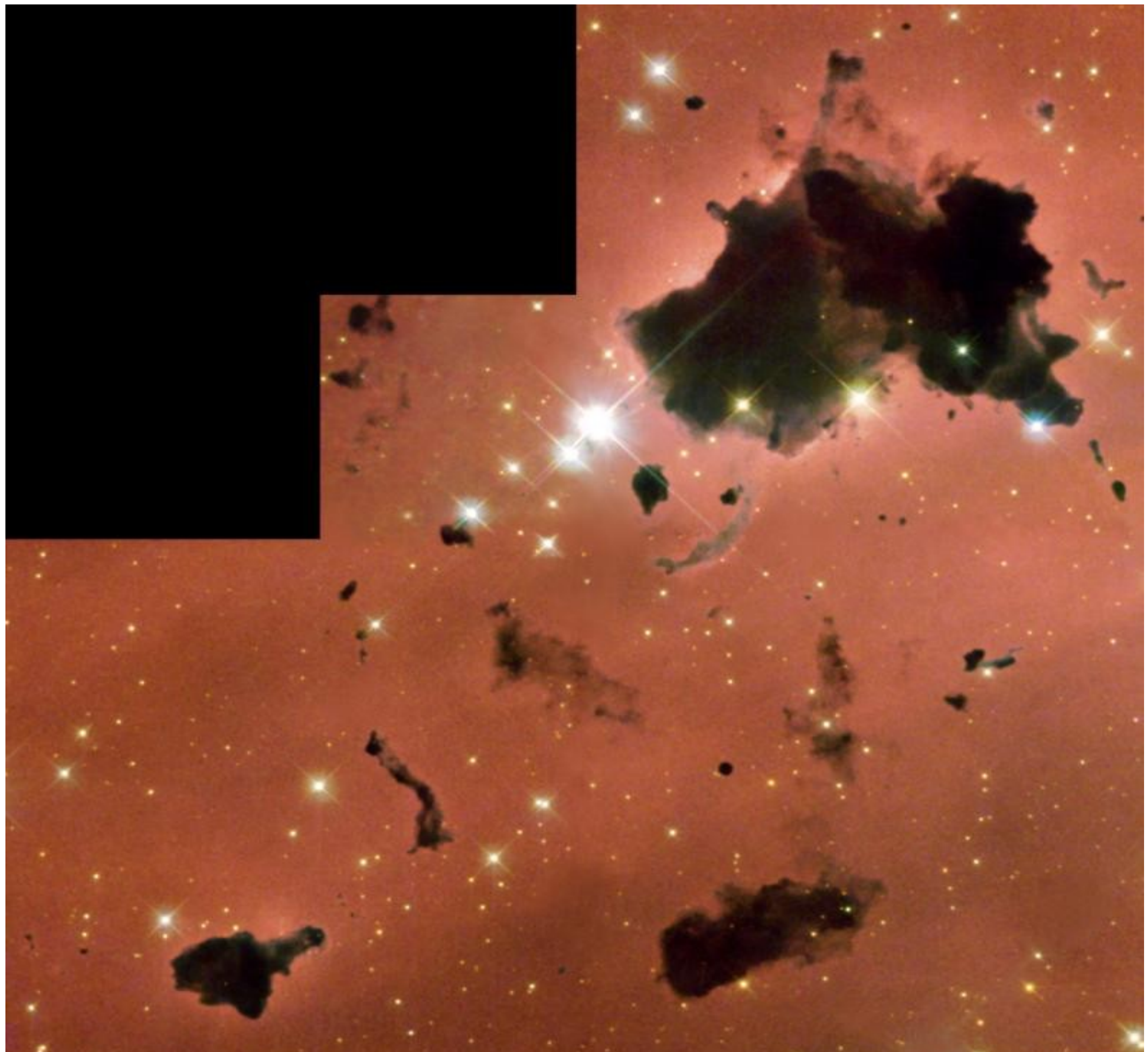


FIG. I

Source: Kapteyn, J. C. (1922).
First Attempt at a Theory of the Arrangement
and Motion of the Sidereal System.
Astrophysical Journal, 55, 302.

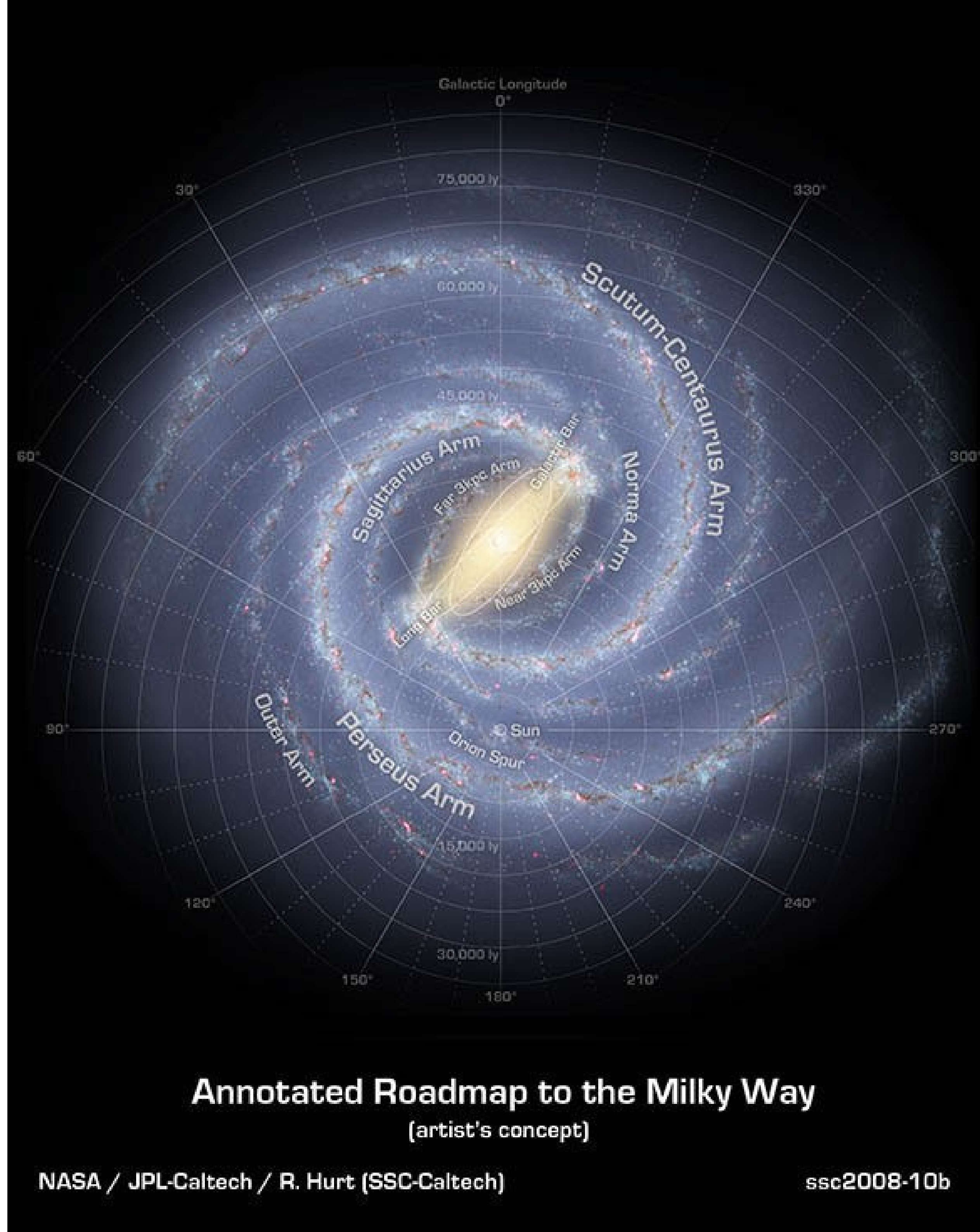
Interstellar extinction

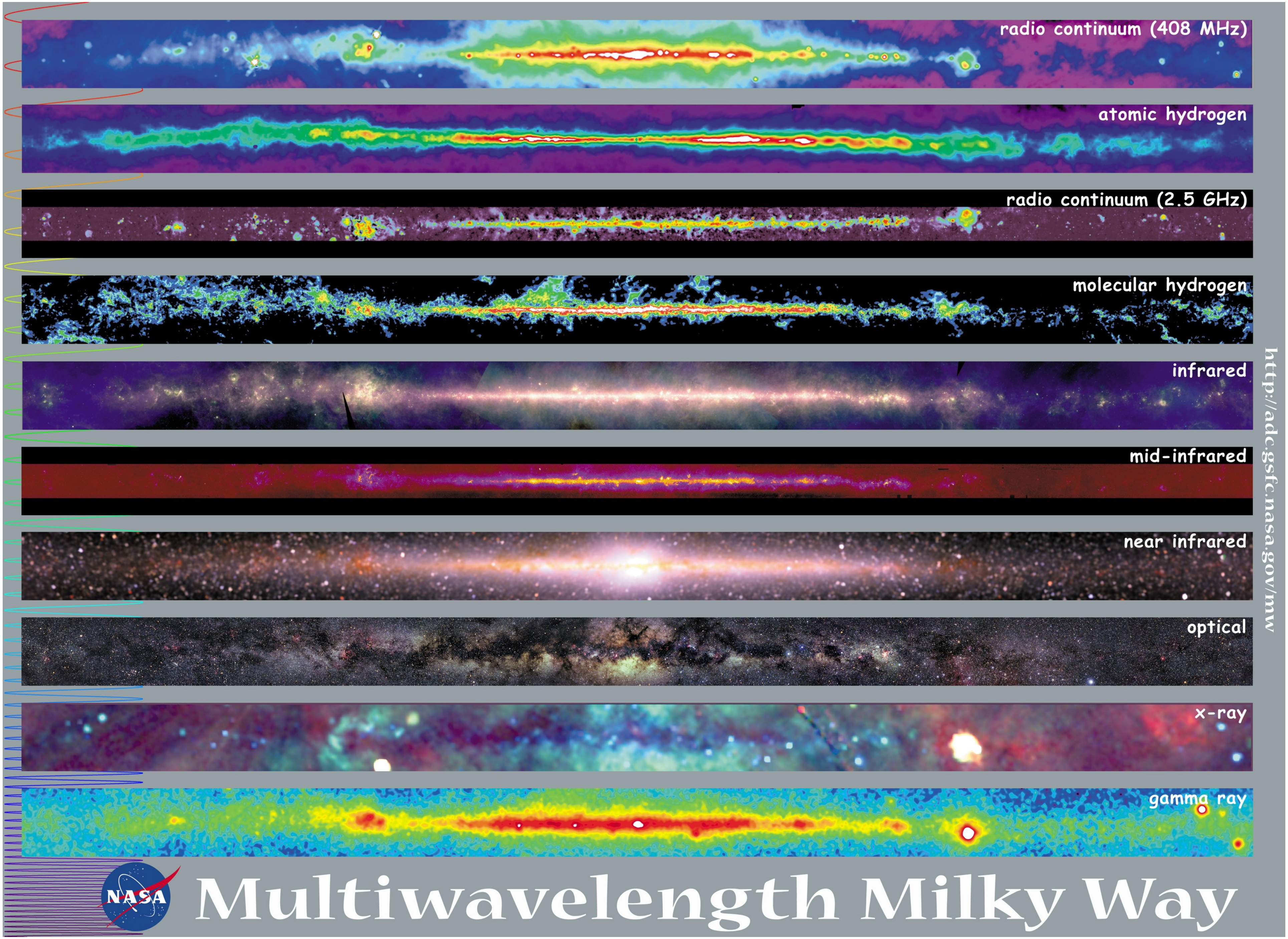


News Release Number: STScI-2002-01

A Modern View of the MW

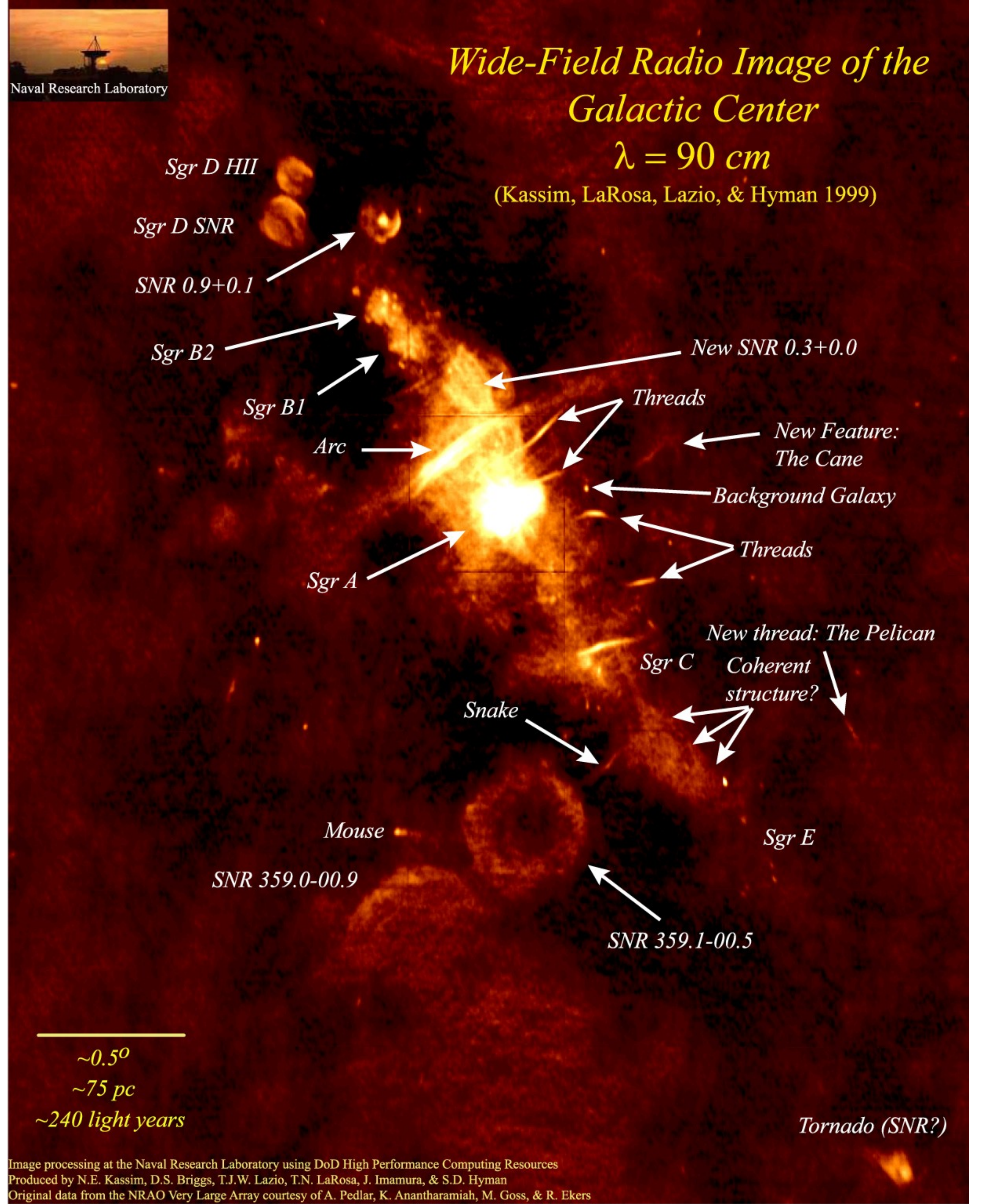
Spitzer Science Center



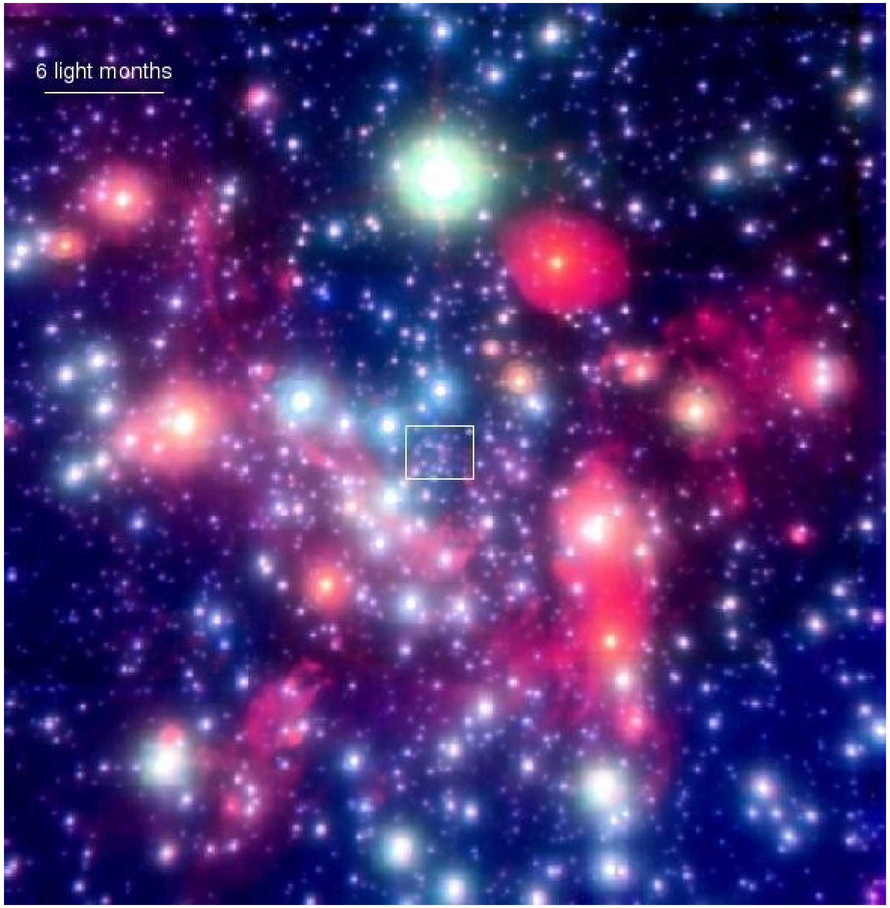


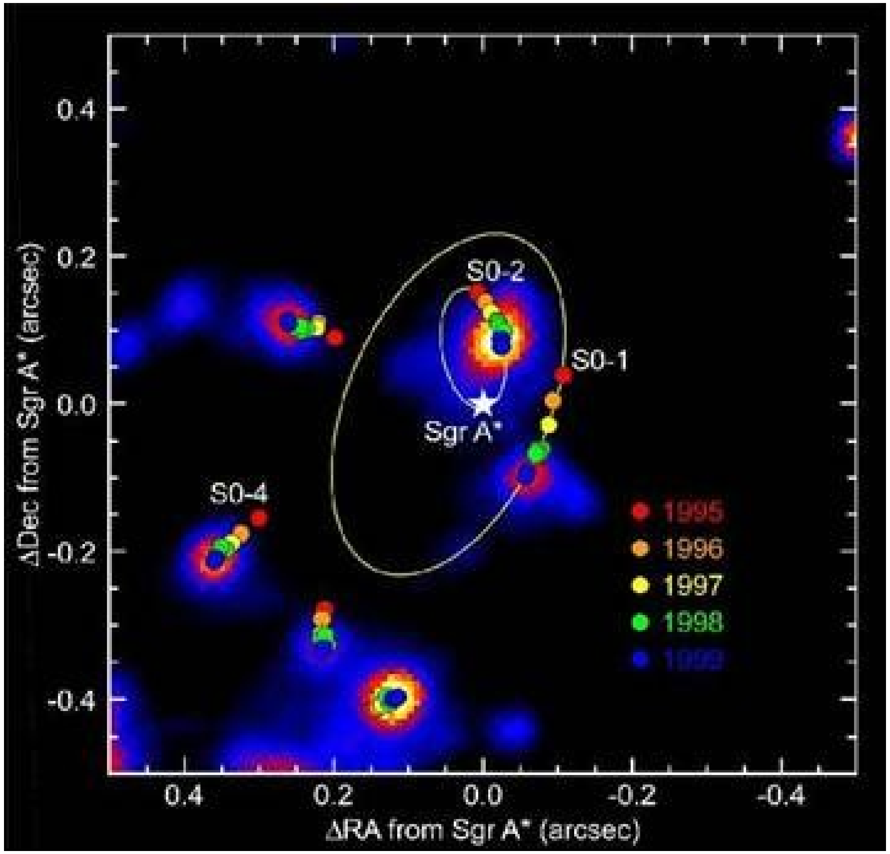
radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
http://adc.gsfc.nasa.gov/mw
NASA
Multiwavelength Milky Way

Center of the MW



Center of the MW cont.

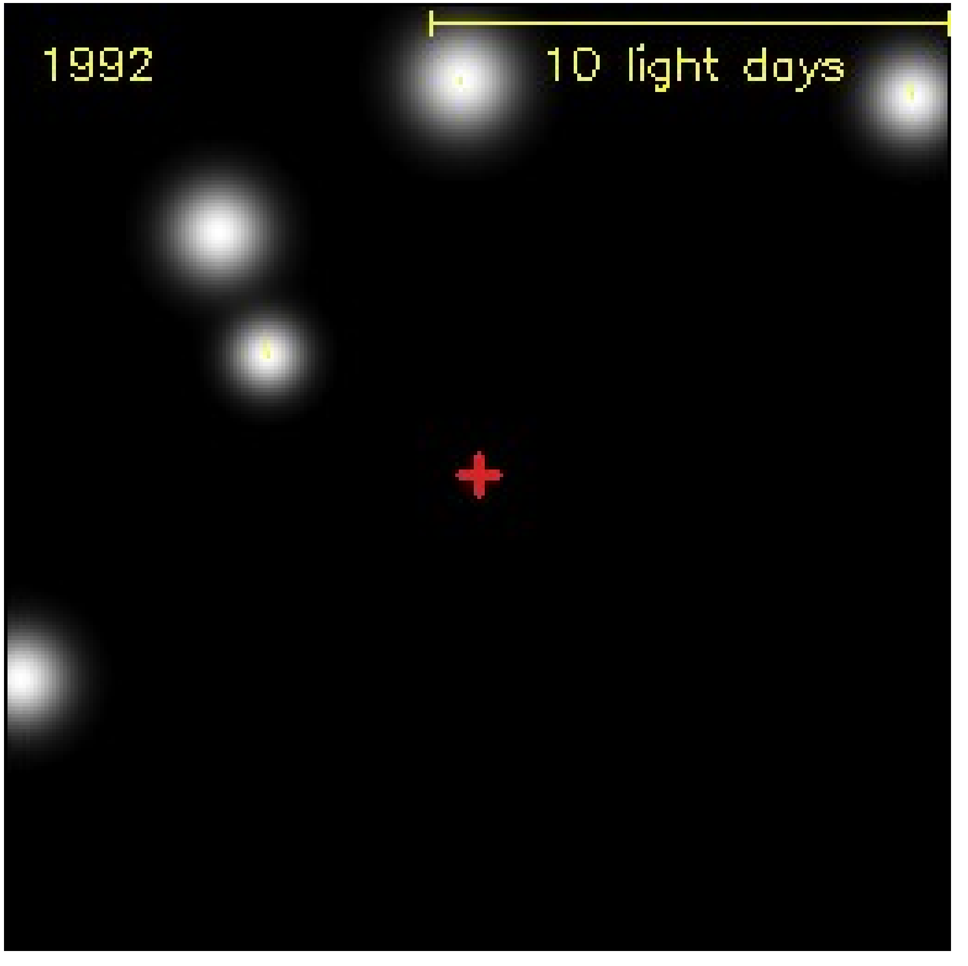




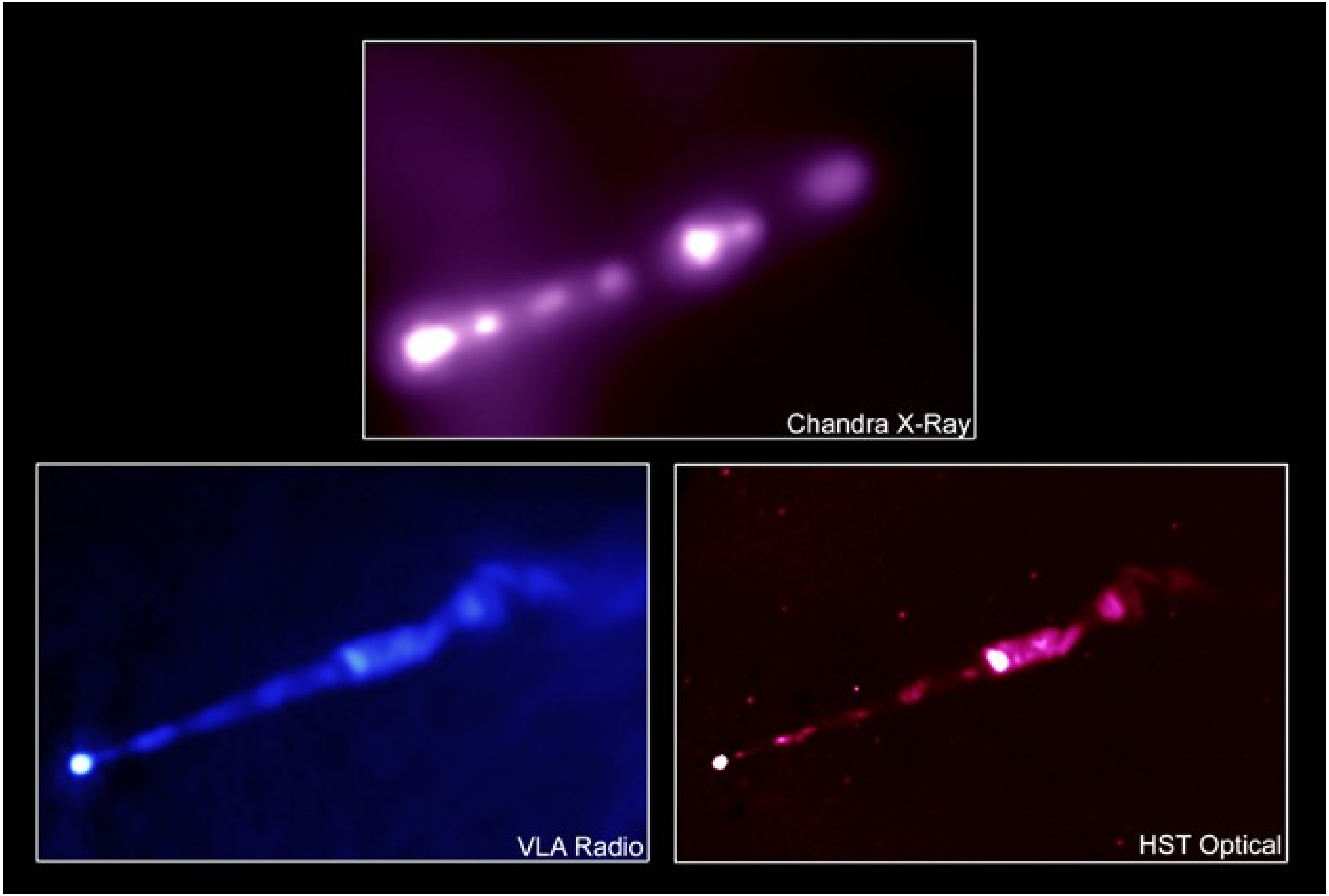
Black Holes

- Region of space from which light is trapped
- Formed in SNe explosions
- Often found in the center of a galaxy
- How do we see it?
  - Can only infer their presence
    - Via gravity
      - How it influences other objects
      - What happens when matter falls into the Black Hole

Black Holes cont.



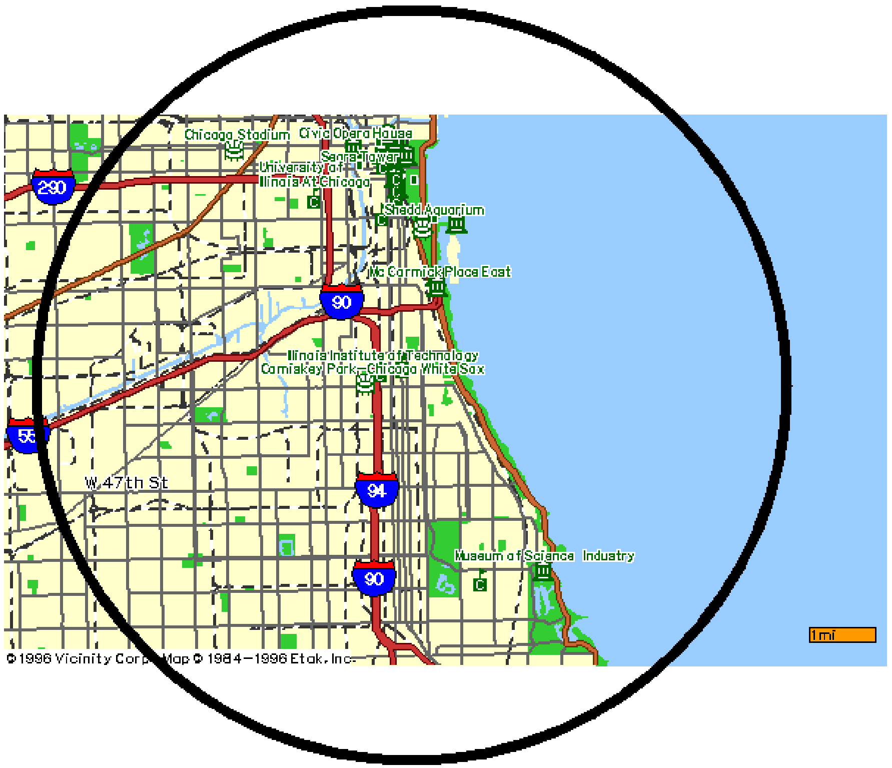
Center of the Elliptical Galaxy M87



Neutron Stars

- Formed in SNe
- Compressed Matter
- Mass = 1.4 M_{sun}

Neutron star vs. Chicago



Mass=1.4 M_{sun}, Radius=10 km
Spin rate up to 38,000 rpm
Density~10^{14} g/cc, Magnetic field~10^{12} Gauss

Observables

- What can we observe about galaxies
  - Light
    - Flux
    - $F = L/(4 \quad d^2)$
      - L is the luminosity of the source
      - d is the distance to the source
  - Fluxes are often reported as a magnitude
    - $m_1 - m_2 = -2.5 \log_{10}(F_1/F_2)$
  - In practice you never measure the entire flux – so what do you do?

Observables 2

- Define a bandpass (BP) and measure the flux there so…
  - $m_{BP} = -2.5 \log_{10}(F_{BP}/F_{V,0})$
  - $F_{V,0}$ is the flux of a magnitude 0 star
    - See table 1.2 pg 21

Observables cont.

- Absolute magnitude
  - Magnitude of an object placed 10 pc from the observer
    - $M = m - 5\log_{10}(d/10pc)$
    - $M-m = 5\log_{10}(d/10pc)$ is called the distance modulus

Observables cont.

- $= D/d$
  - is in radians(small angle approximation)
- $F = \int^{\infty}_{0} F(\ )d\nu = \int^{\infty}_{0} F(\ )d$
  - Bolometric flux

map. Fig. 2 shows the passbands realised by Olson (1974).

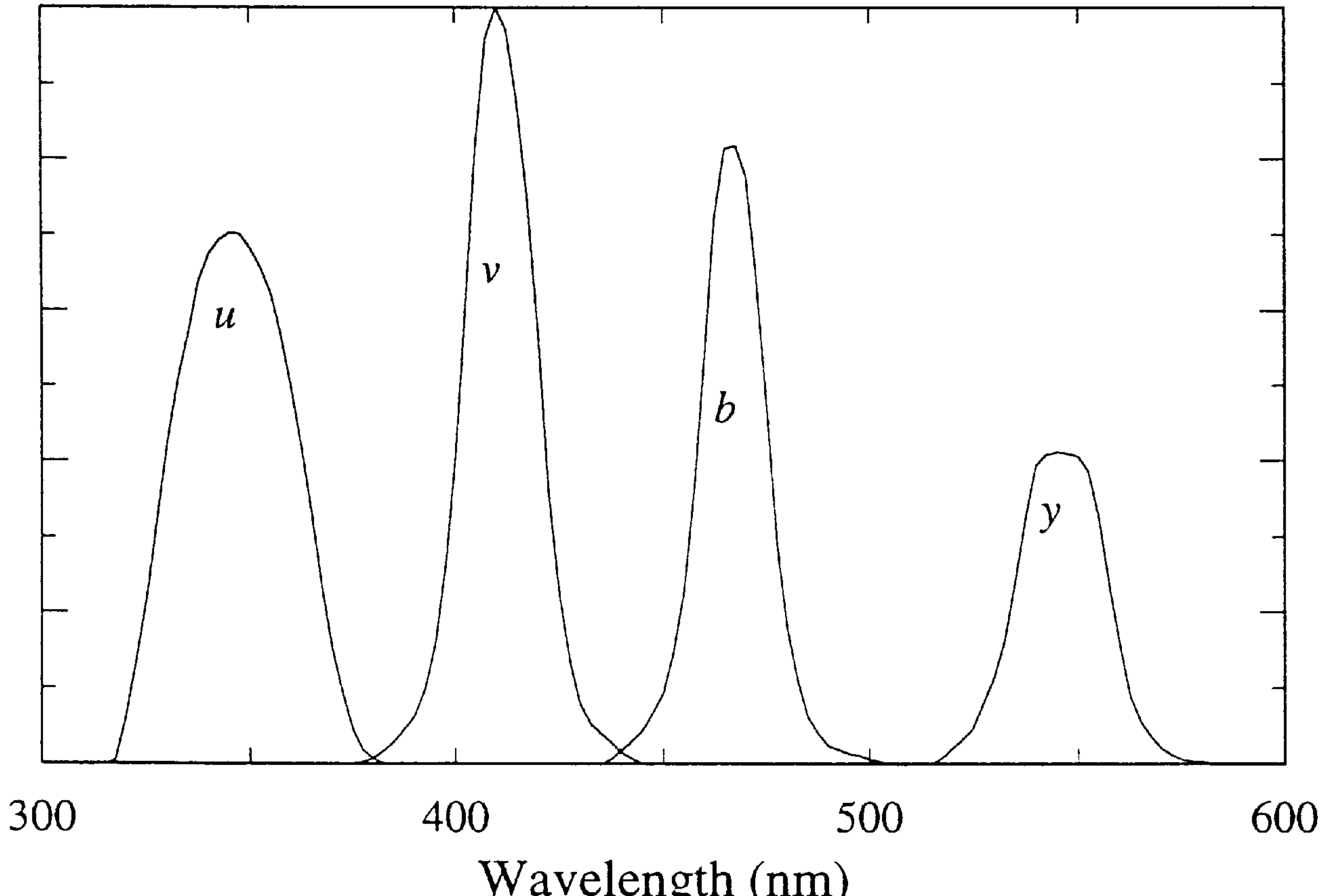


Figure 2. The uvby passbands of the Stromgren 4-colour system

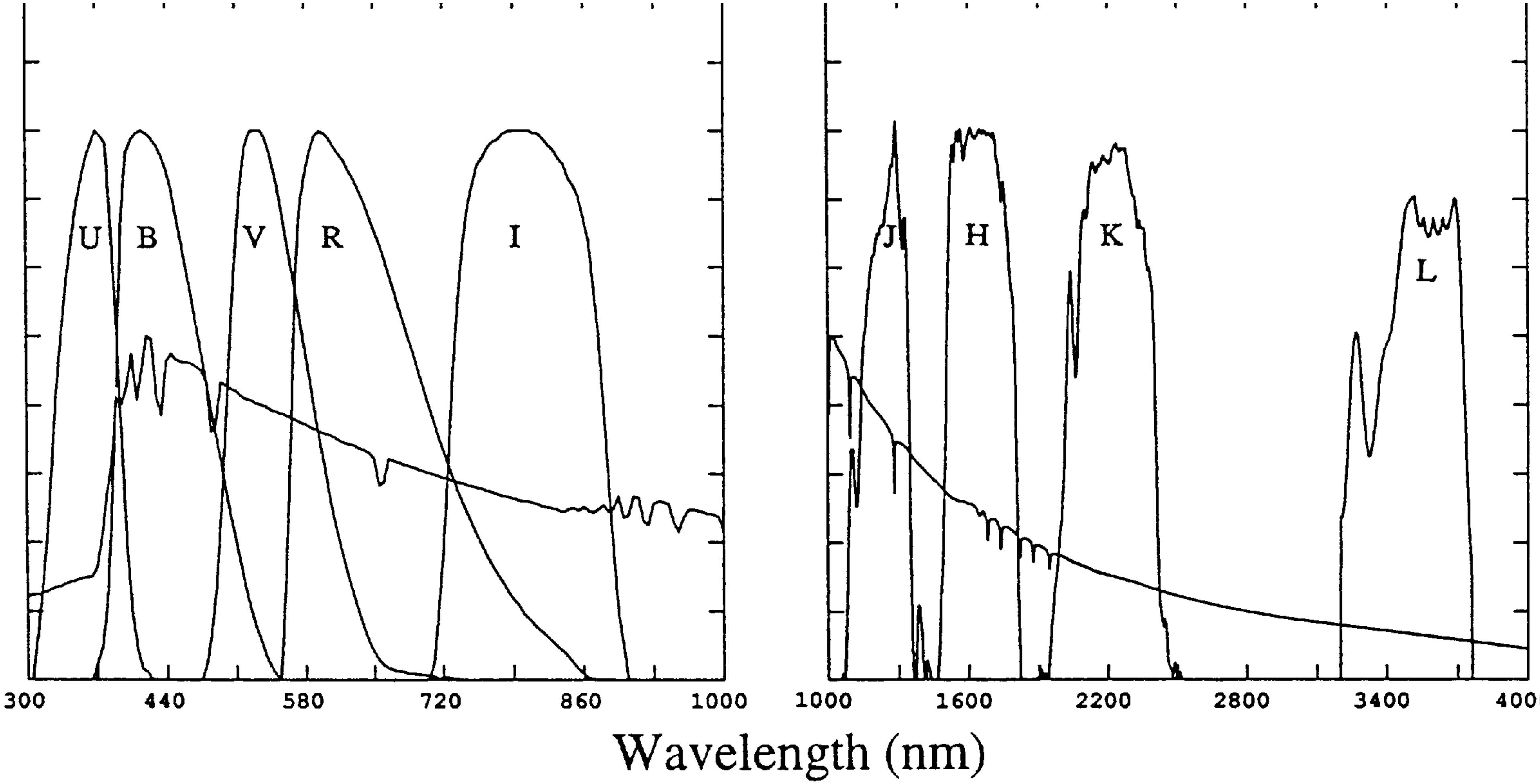
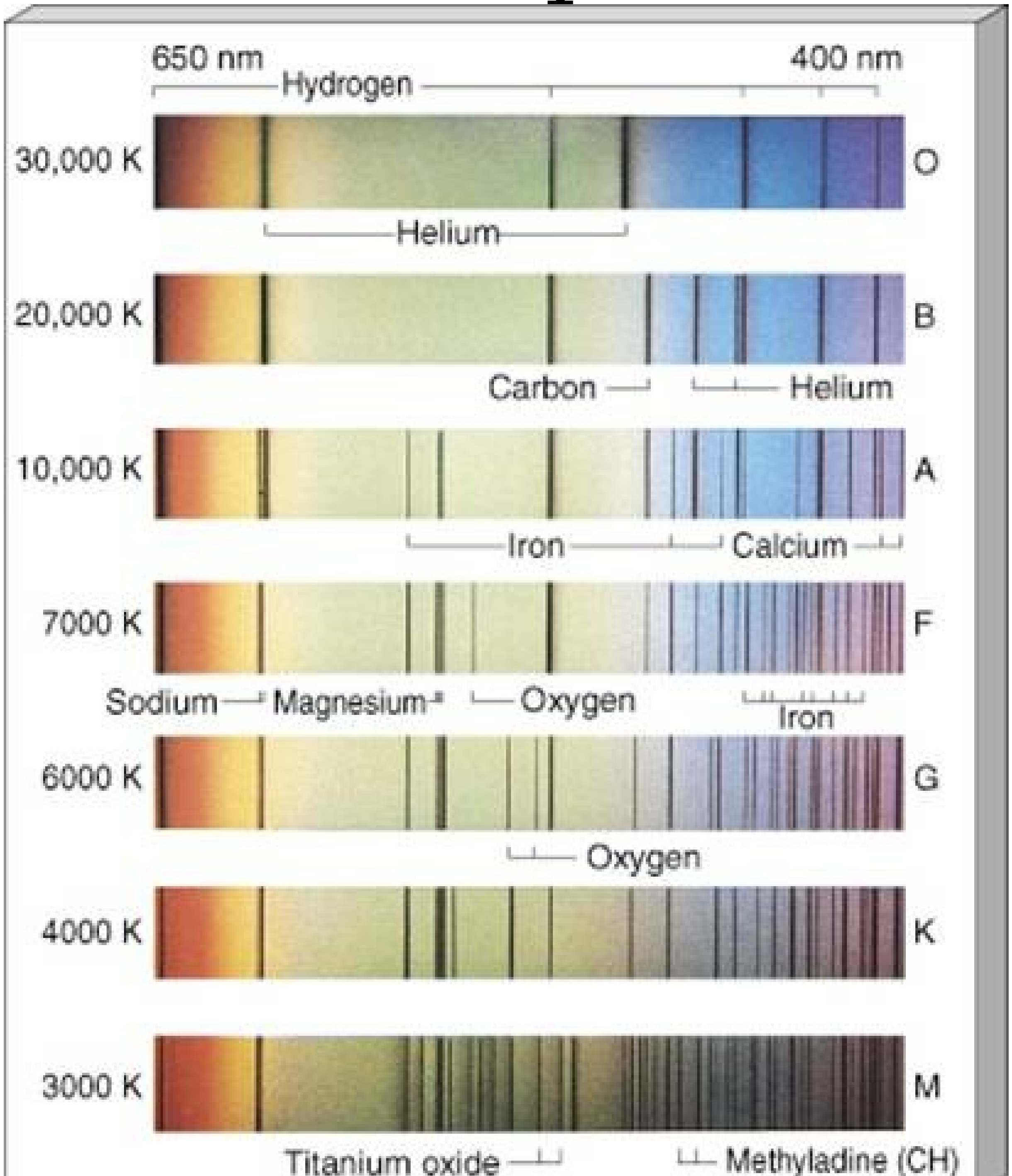


Table 1. Johnson-Cousins-Glass UBVRIJHKLM System

	U	B	V	R	I	J	H	K	L	M
λeff(nm)	367	436	545	638	797	1220	1630	2190	3450	4750
$\Delta\lambda$(nm)	66	94	88	138	149	213	307	390	472	460
F_ν(V=0) (10^{-30}Wcm^{-2}hz^{-1})	1780	4000	3600	3060	2420	1570	1020	636	281	154

Stellar Spectra



Stellar Spectra

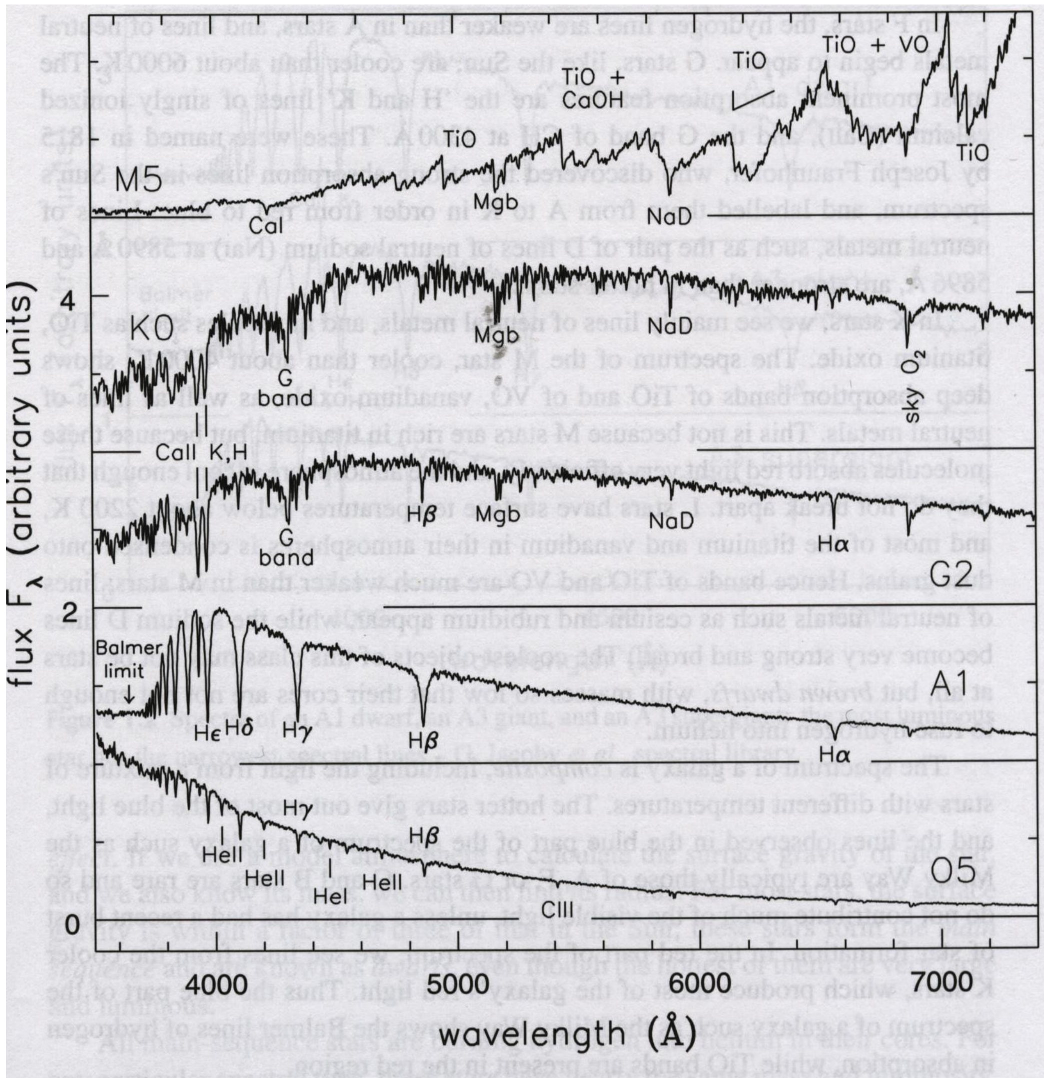
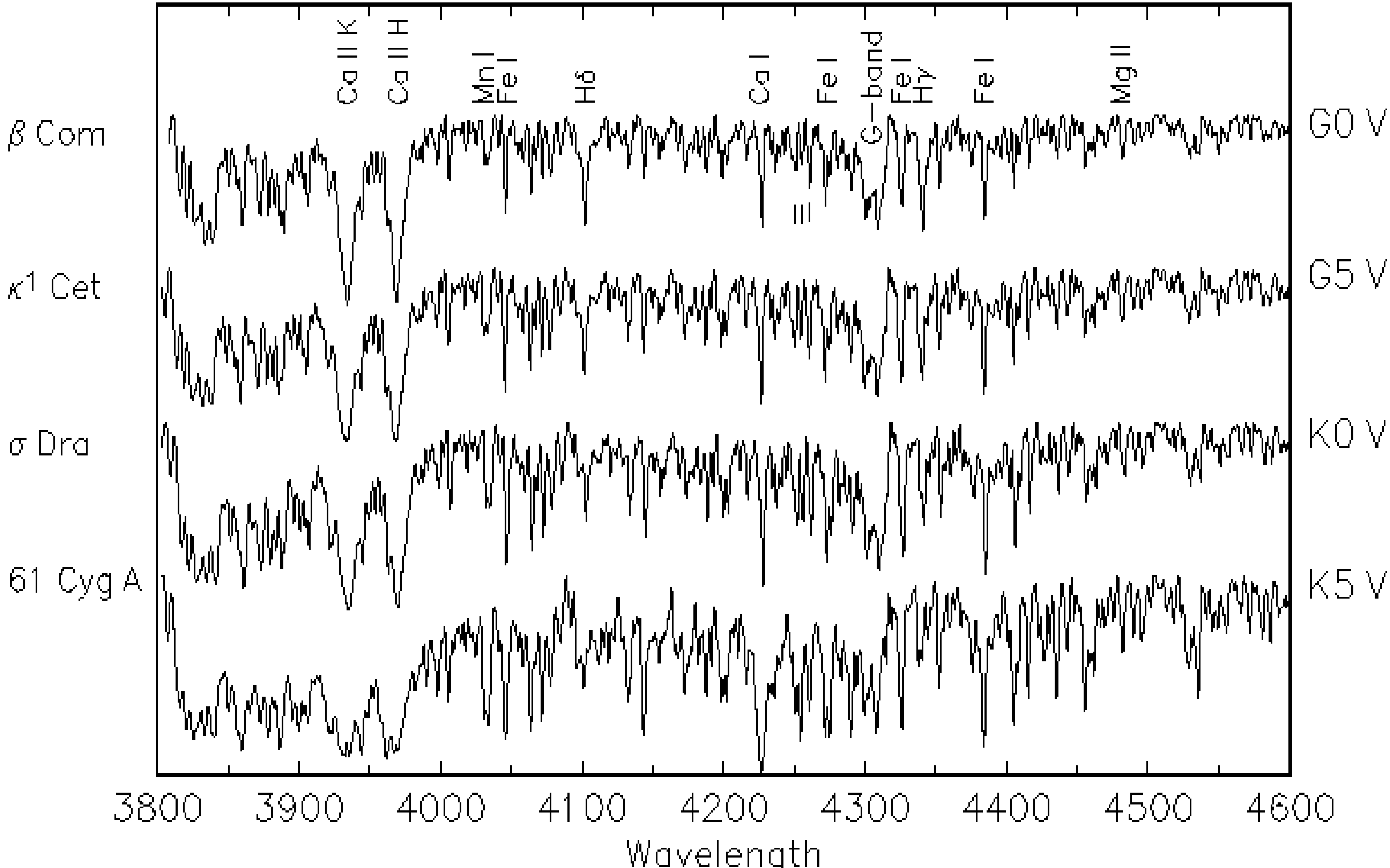


Figure 1.1 Optical spectra of main-sequence stars with roughly the solar chemical composition. From the top in order of increasing surface temperature, the stars have spectral classes M5, K0, G2, A1, and O5 – G. Jacoby *et al.*, spectral library.

Classification

Stellar spectra were studied for years before Antonia Maury realized that she could order the spectral types in order of their line strengths to form a spectral sequence.

Main Sequence G0 – K5



The modern stellar spectral classification scheme (also known as the Harvard Spectral Classification Scheme) was created by Annie Jump Cannon through her examination of spectra from 1918 to 1924. Originally, the scheme used capital letters running alphabetically, but was later reordered to reflect the surface temperatures of stars. In order of decreasing temperature, these types were O, B, A, F, G, K. and M. According to astronomical myth, Henry Norris Russell suggested the following mnemonic to assist students in remembering the scheme:

Oh Be A Fine Girl, Kiss Me!

Mnemonics for the Harvard Spectral Classification Scheme

Oh Bother, Astronomers Frequently Give Killer Midterms.

Overseas [Bulletin/Broadcast]: A Flash! Godzilla Kills Mothra!

One Bug Ate Five Green Killer Moths.

If you want more mnemonics you can look at

http://www.star.ucl.ac.uk/~pac/obafgkmrns.html

- Spectra also show the effects of surface gravity
- Stronger gravity makes broader lines

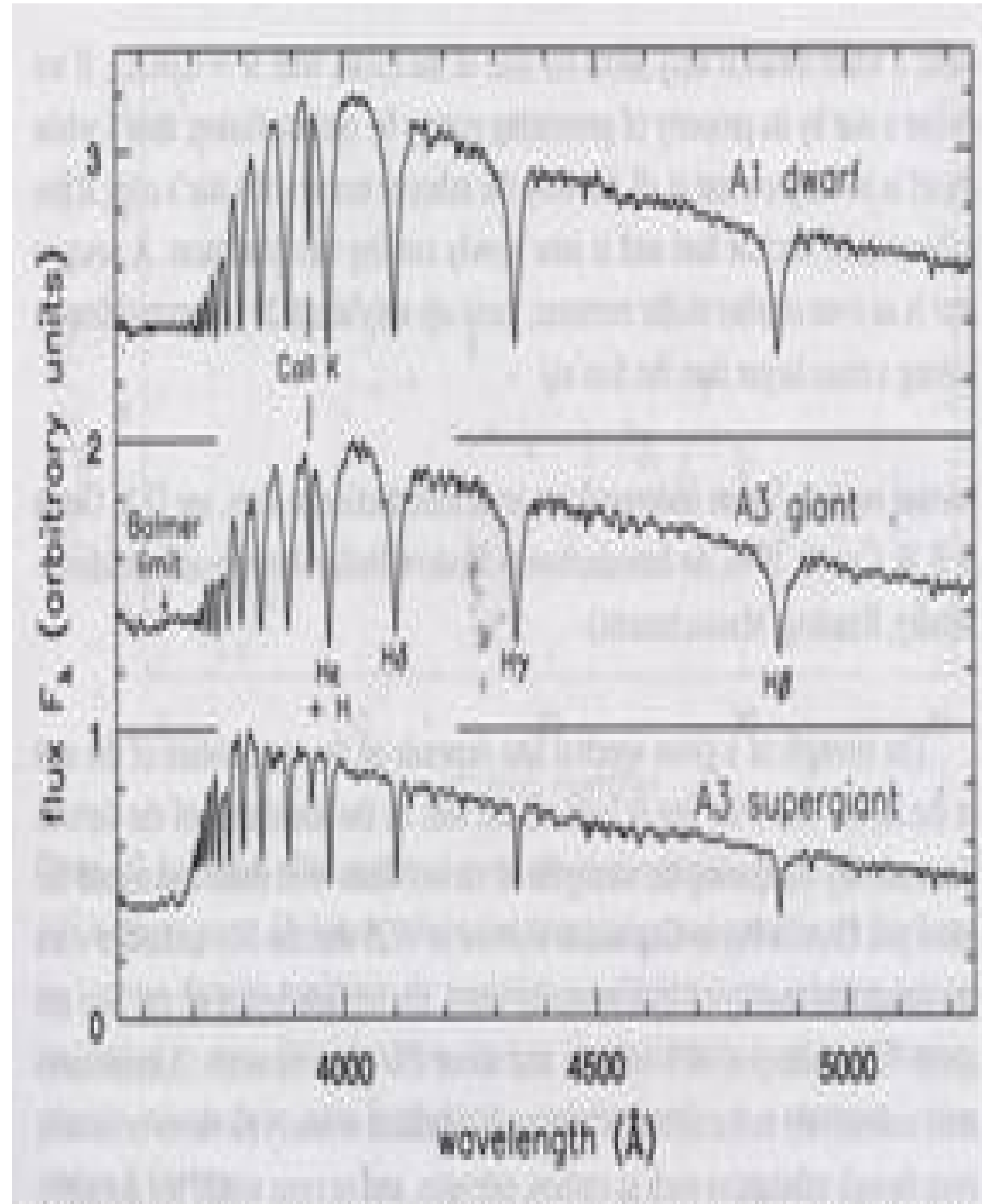
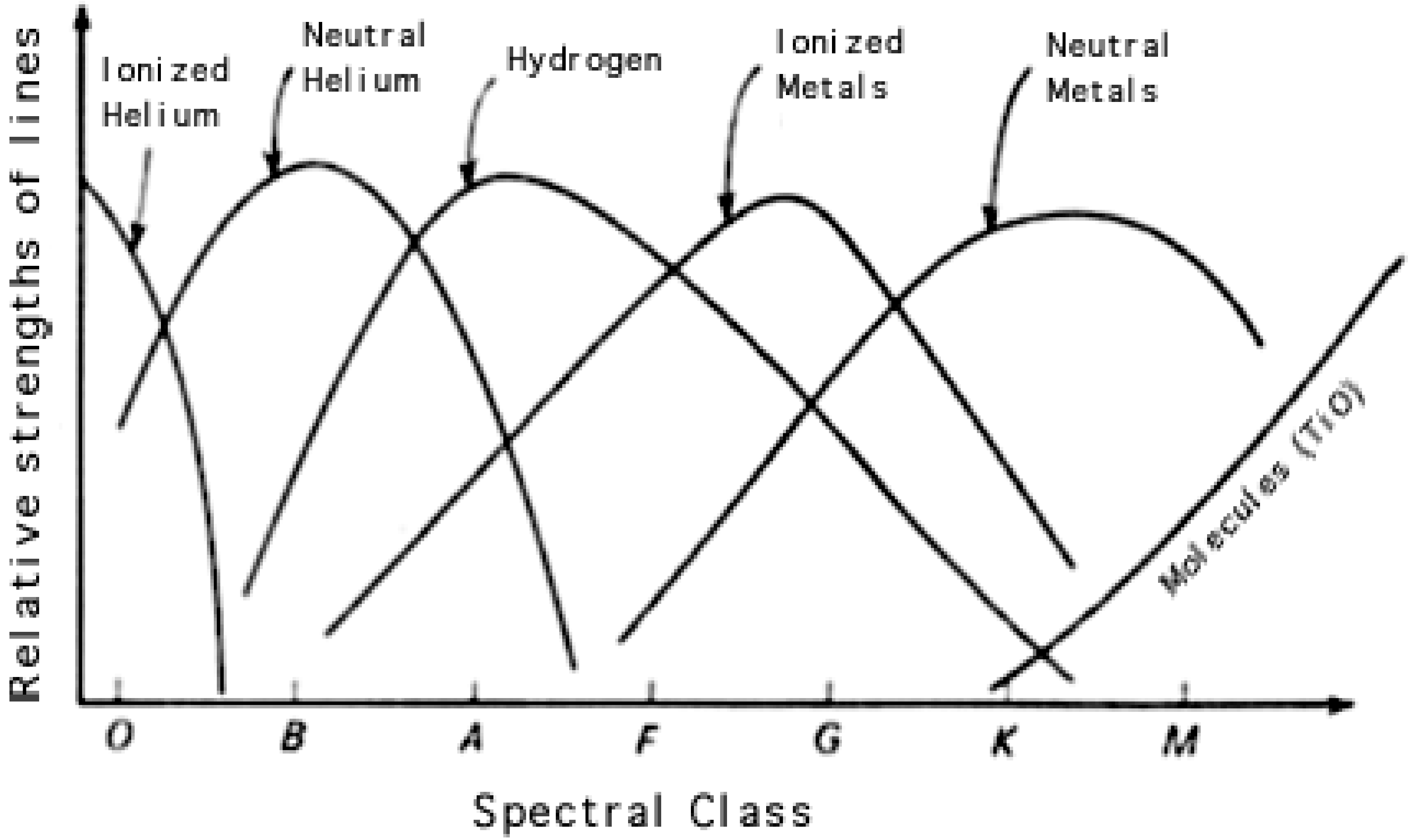
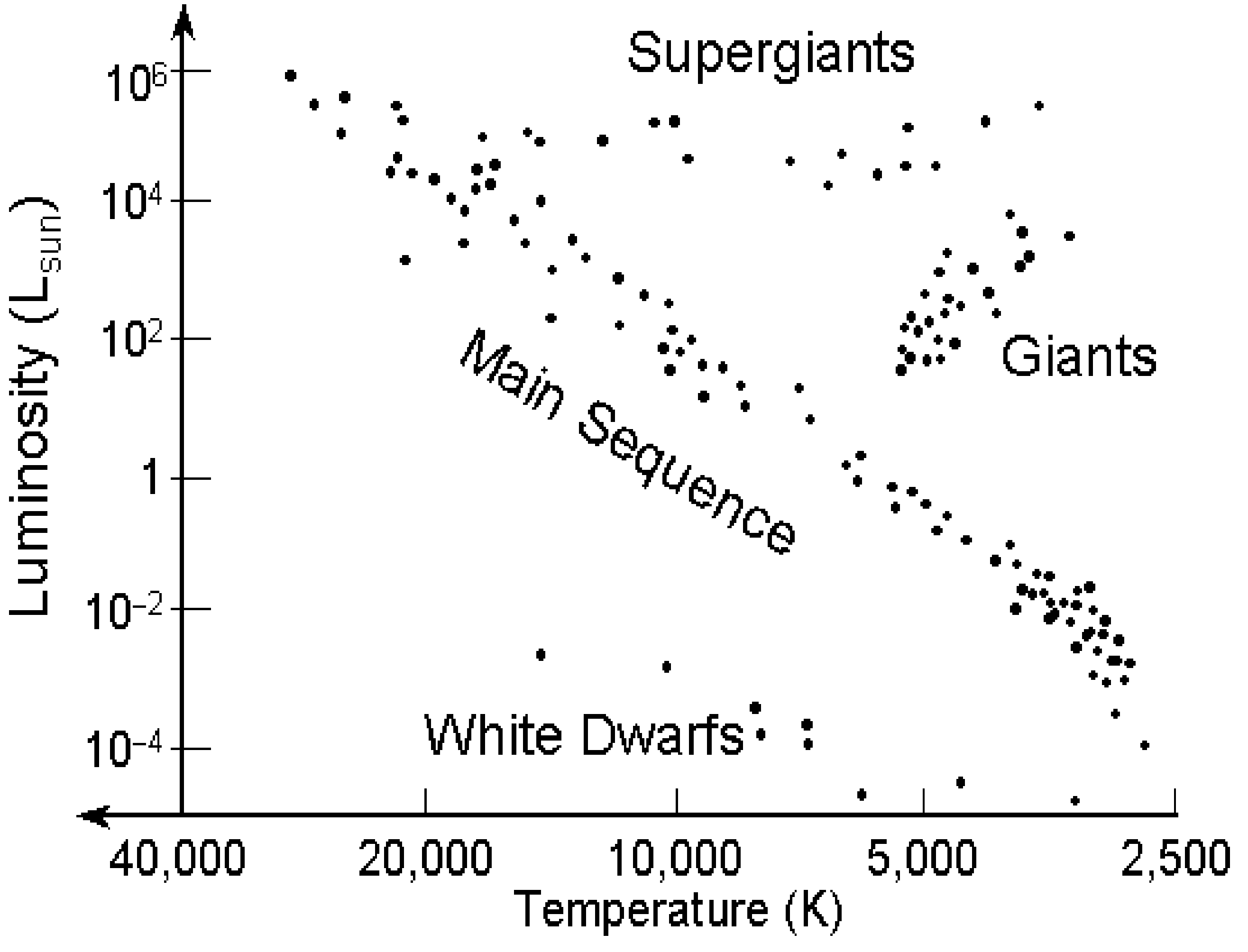


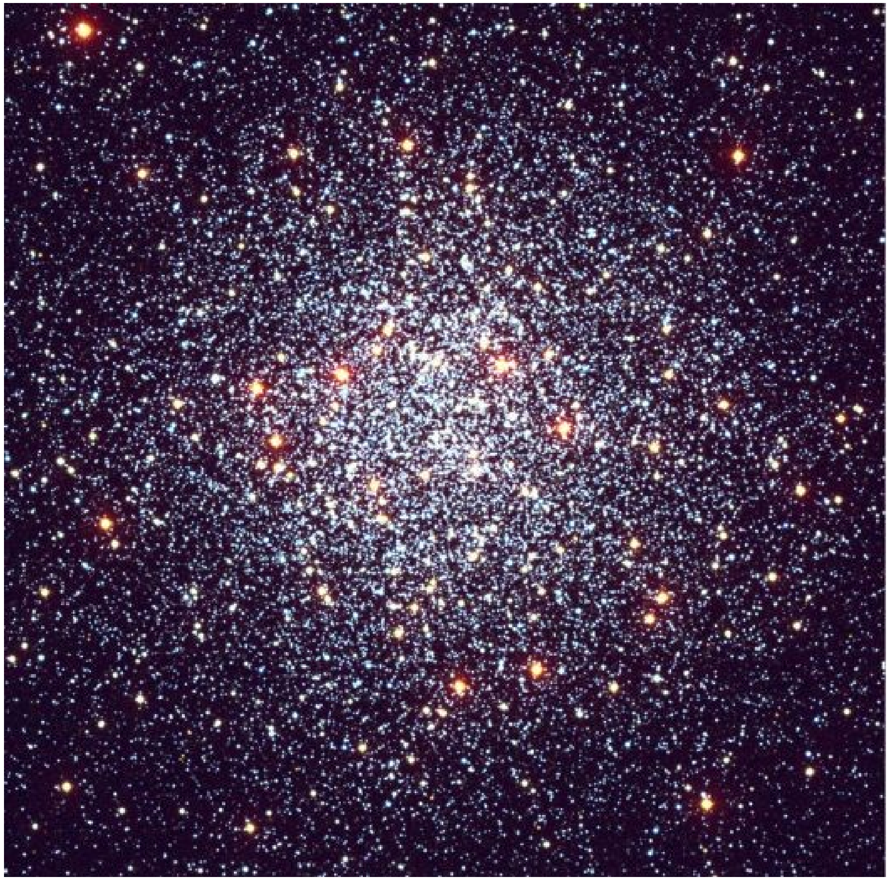
Figure 1.2 Spectra of an A1 dwarf, an A3 giant, and an A3 supergiant: the most luminous star has the narrowest spectral lines – G. Jacoby *et al.*, spectral library.

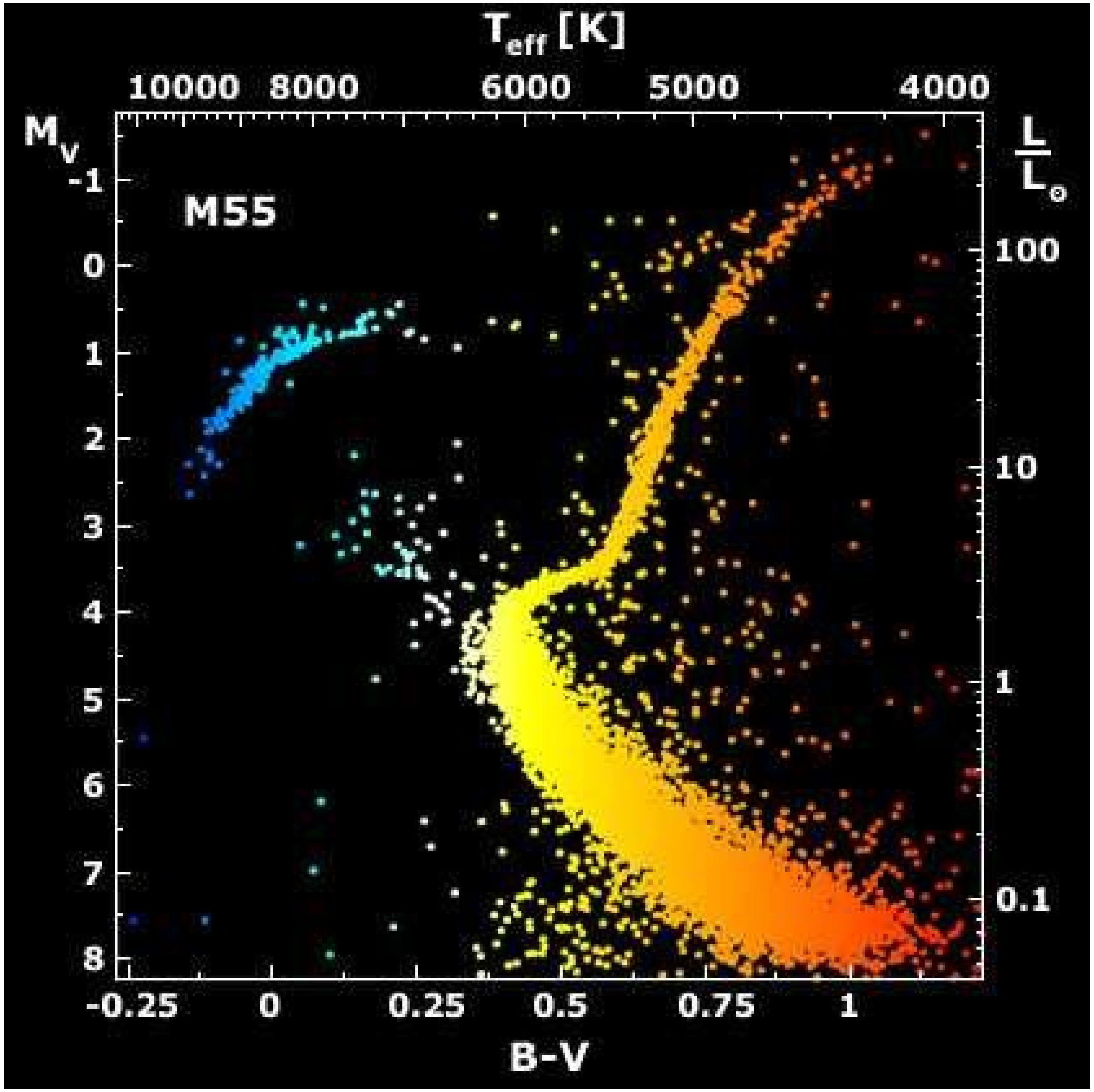

Relative strengths of lines
Ionized Helium
Neutral Helium
Hydrogen
Ionized Metals
Neutral Metals
Molecules (TiO)
O
B
A
F
G
K
M
Spectral Class

Hertzsprung – Russell diagram

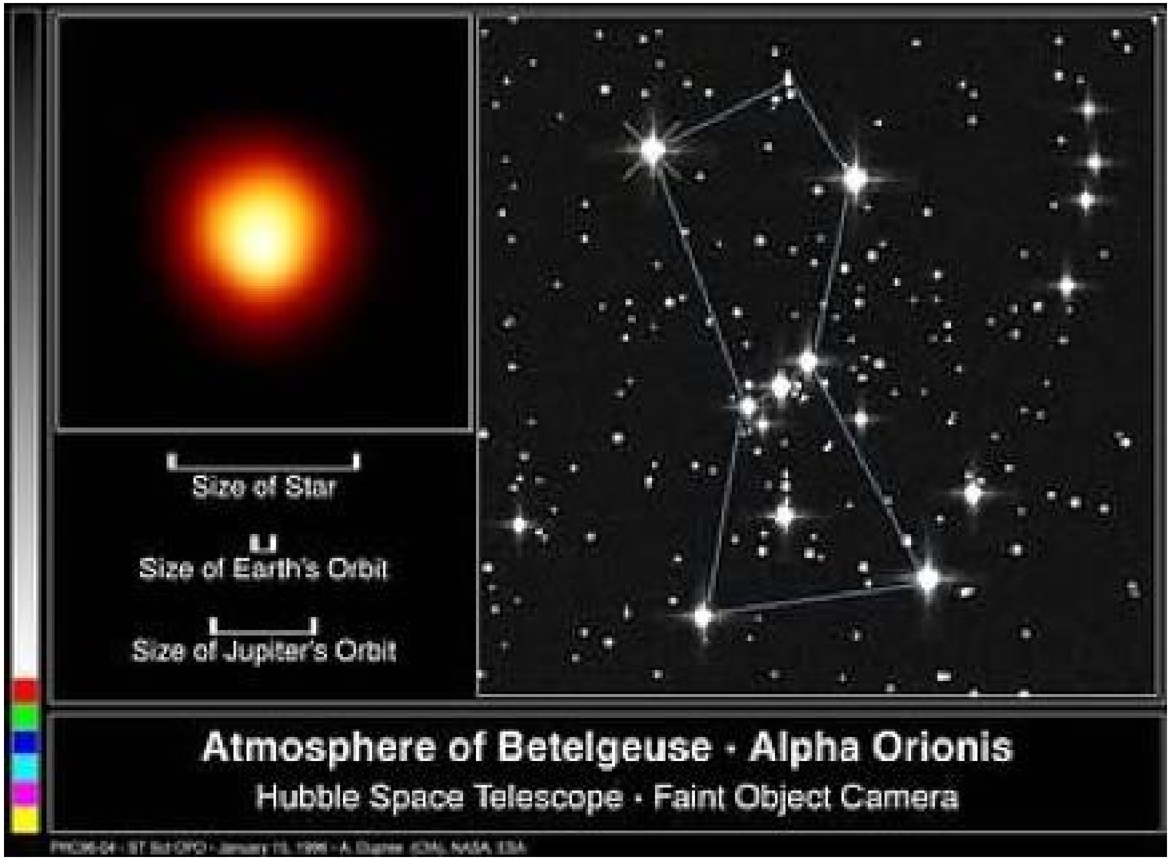


H-R diagram for a globular cluster M55





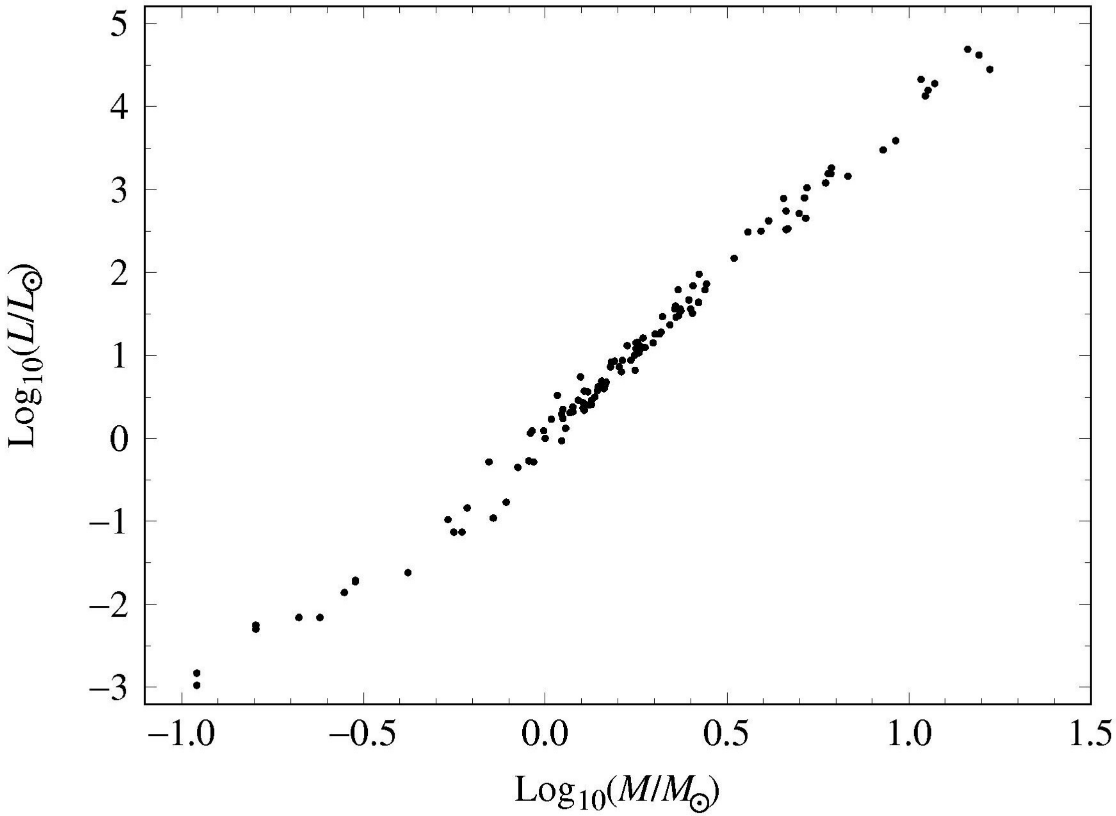
Radii are very difficult to measure because stars are so far away.



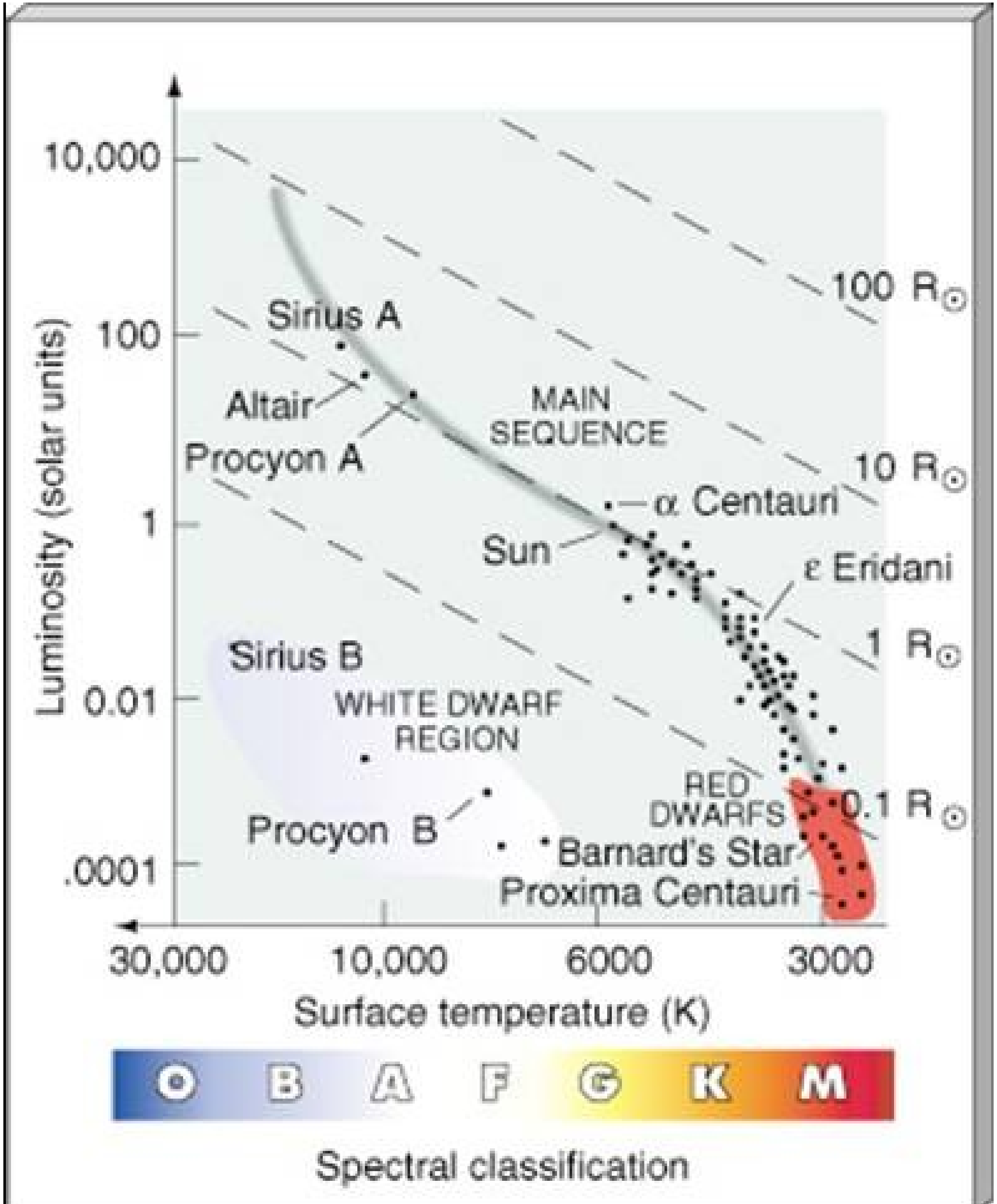
Methods:

* Interferometry (single stars)
* Lunar Occultation (single stars)
* Eclipsing binaries (need distance)
* Imaging

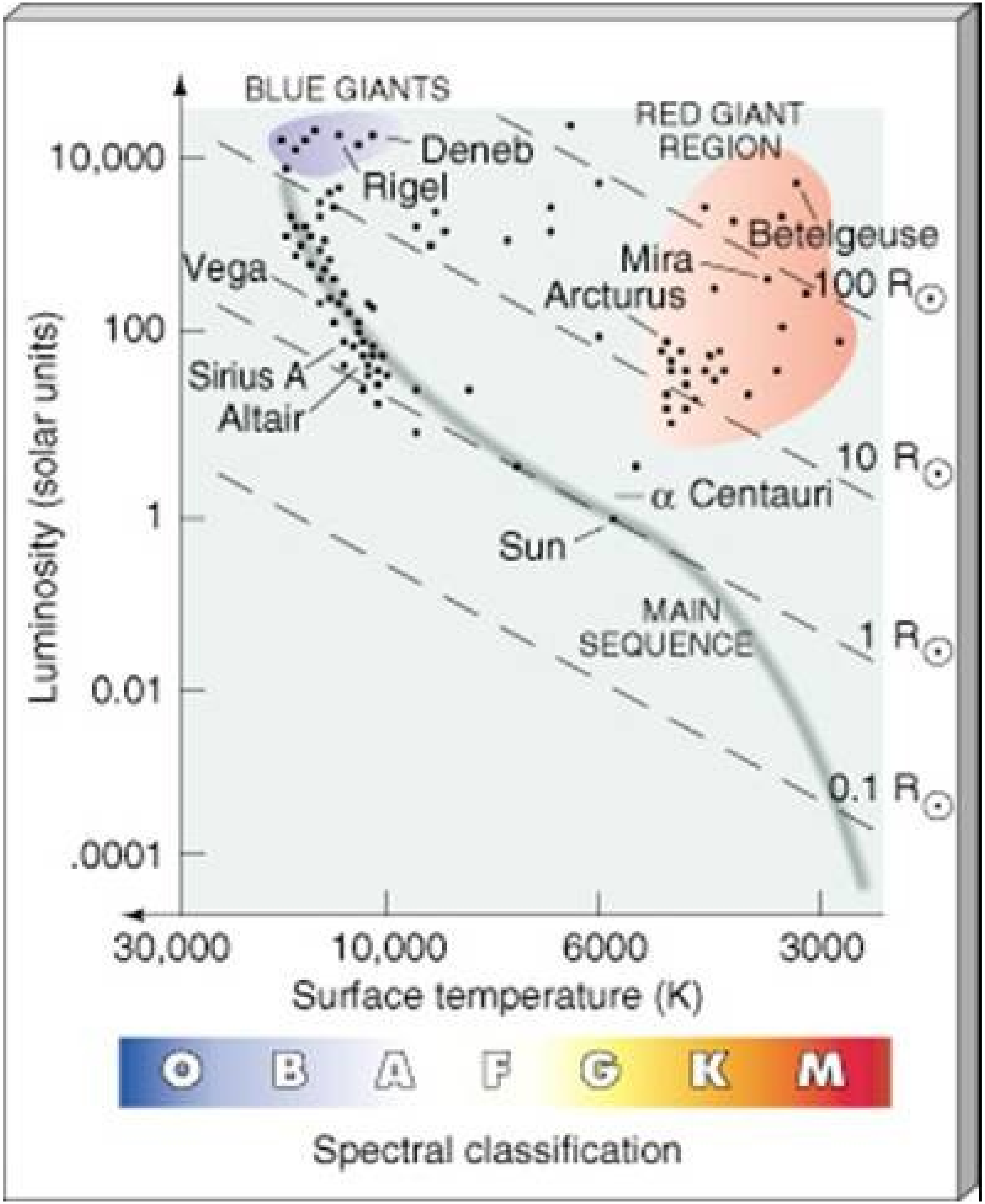
Luminosity – Mass relation



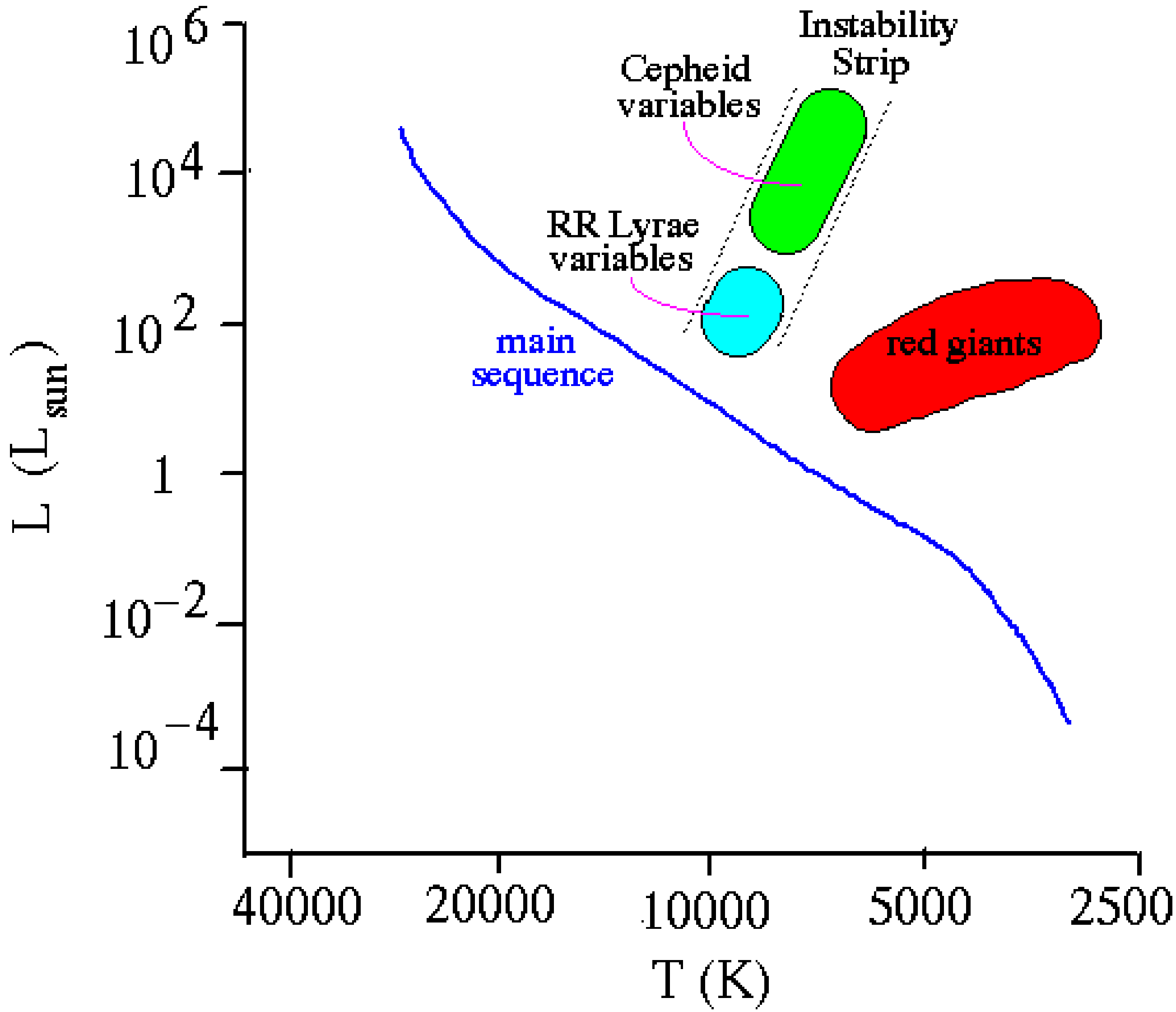
$$R \propto R_{\odot}\left(\frac{M}{M_{\odot}}\right)^{\alpha}, L \propto L_{\odot}\left(\frac{M}{M_{\odot}}\right)^{\beta}$$



10,000
100
1
0.01
.0001
Luminosity (solar units)
100 R⊙
10 R⊙
1 R⊙
0.1 R⊙
Sirius A
Altair
Procyon A
MAIN
SEQUENCE
α Centauri
Sun
ε Eridani
Sirius B
WHITE DWARF
REGION
Procyon B
RED
DWARFS
Barnard's Star
Proxima Centauri
30,000
10,000
6000
3000
Surface temperature (K)
O
B
A
F
G
K
M
Spectral classification

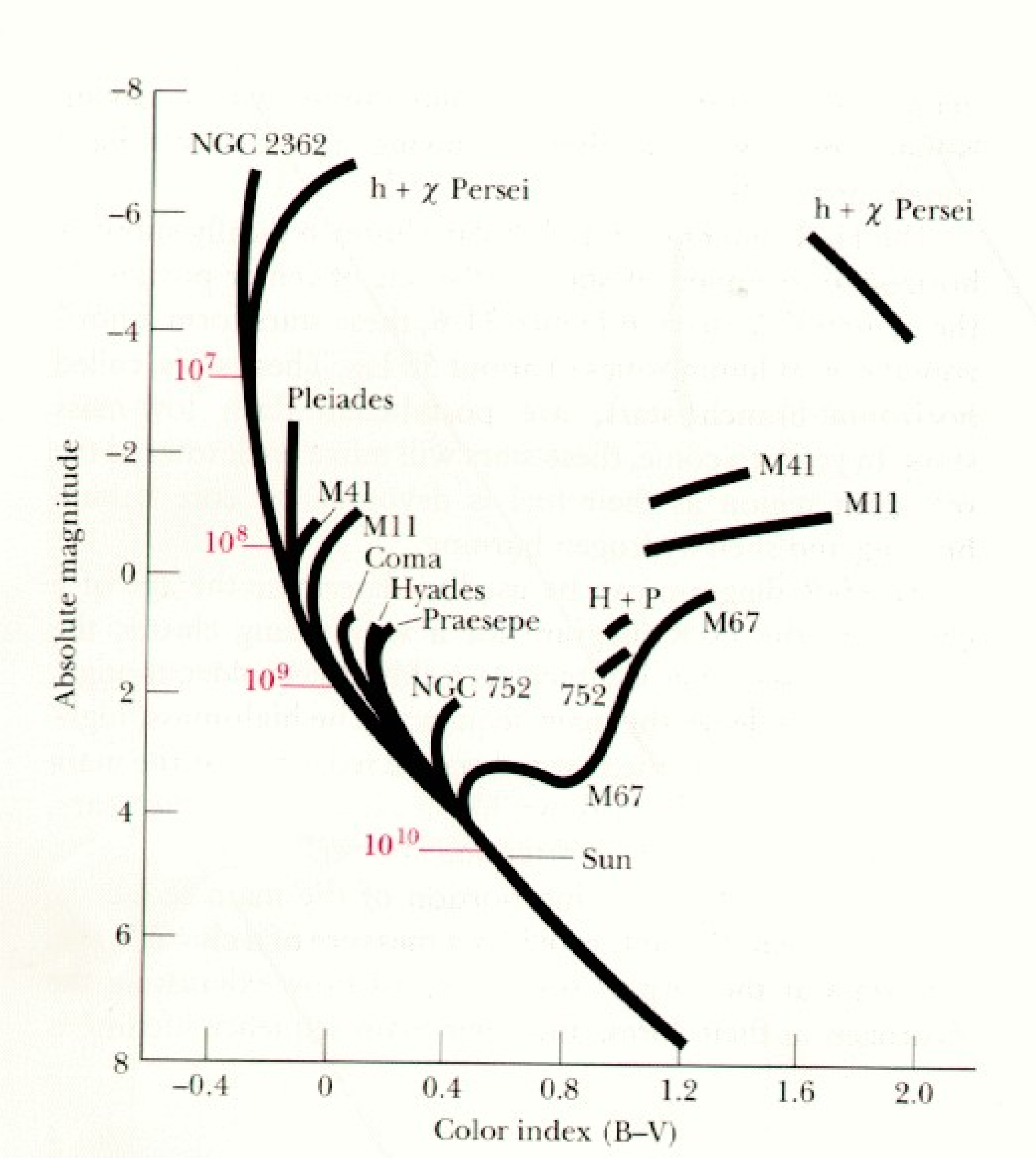


BLUE GIANTS
RED GIANT REGION
Deneb
Rigel
Betelgeuse
Mira
Arcturus
Vega
100 R⊙
Sirius A
Altair
10 R⊙
α Centauri
Sun
MAIN SEQUENCE
1 R⊙
0.1 R⊙
Luminosity (solar units)
10,000
100
1
0.01
.0001
30,000
10,000
6000
3000
Surface temperature (K)
O
B
A
F
G
K
M
Spectral classification



L (L_sun)
10^6
10^4
10^2
1
10^-2
10^-4
40000
20000
10000
5000
2500
T (K)
main sequence
Cepheid variables
Instability Strip
RR Lyrae variables
red giants

Why does the H-R diagram look like it does?



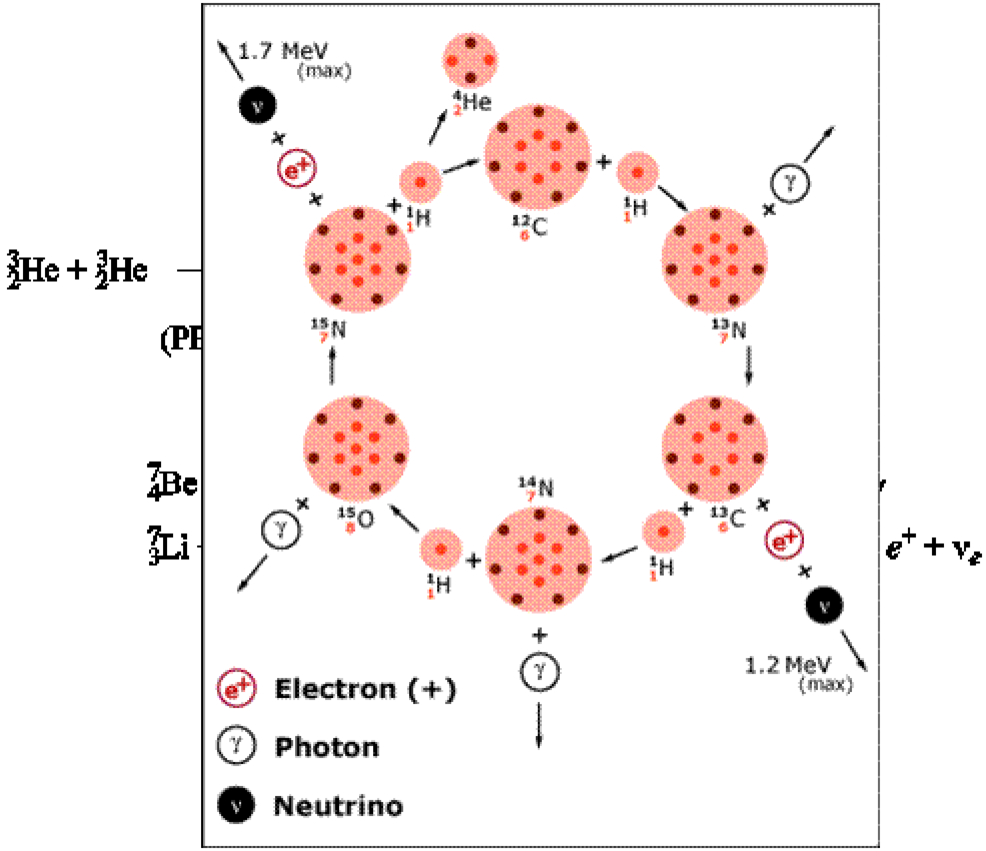
Proton-Proton cycle
T~8x10^6 K

$${}^1_1H + {}^1_1H \longrightarrow {}^2_1H + e^+ + \nu \quad (1.19\ MeV)$$

$${}^1_1H + {}^2_1H \longrightarrow {}^3_2He + \gamma \quad (5.49\ MeV)$$

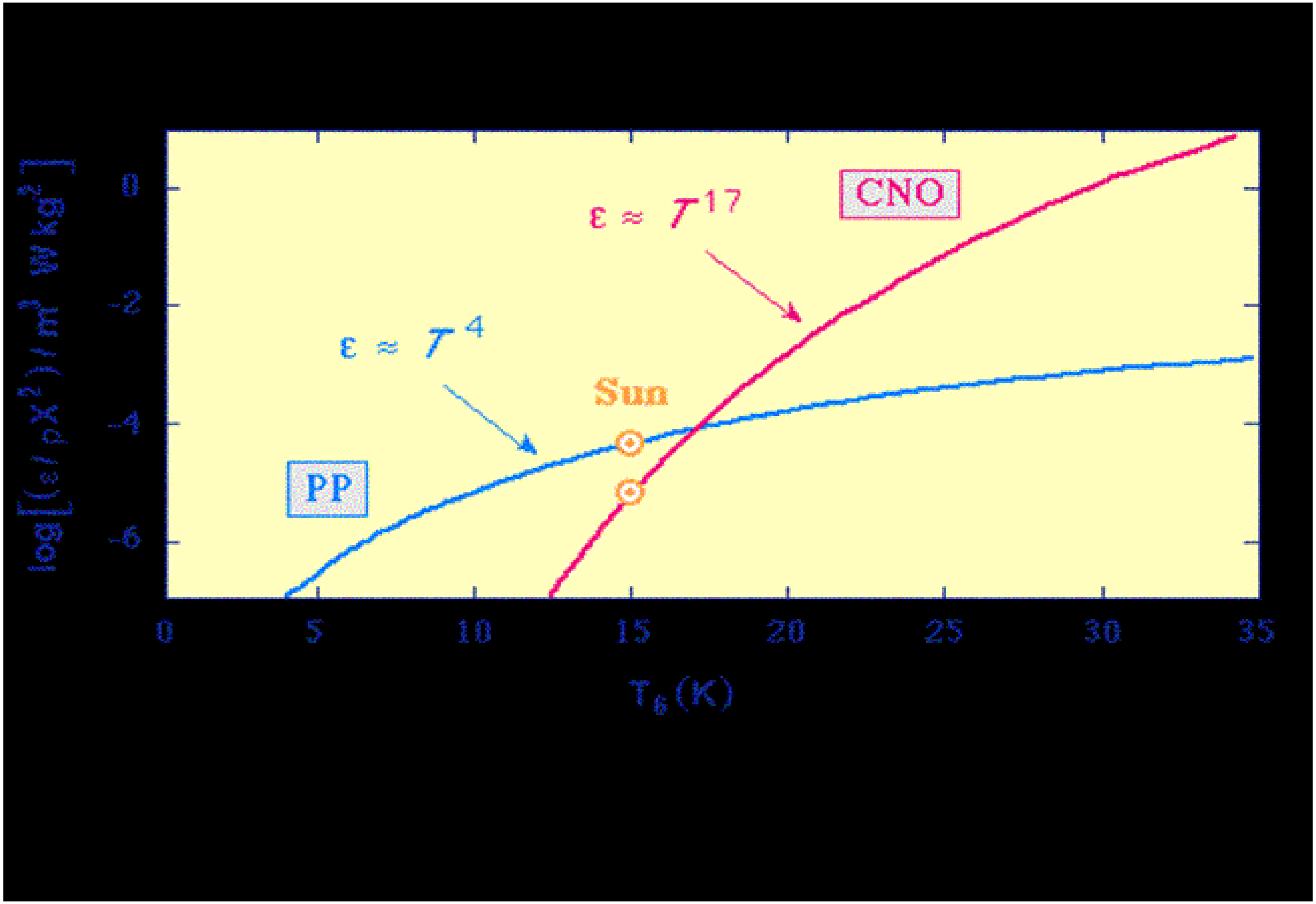
$${}^3_2He + {}^3_2He \longrightarrow {}^4_2He + {}^1_1H + {}^1_1H \quad (12.85\ MeV)$$

C-N-O cycle
T~2x10^7 K



Stellar Fusion

- Fusion products have less mass that the particles that were fused
  - Since $e=mc^2$ fusion turns mass into energy
- But atomic nuclei have positive charges which repel
  - Therefor need high temperature and density to “force” the nuclei together
  - More charge higher temperature and pressure



- Sun's energy is primarily from the P-P reactions
- If M> 1.5 M_{sun} C-N-O cycle dominates

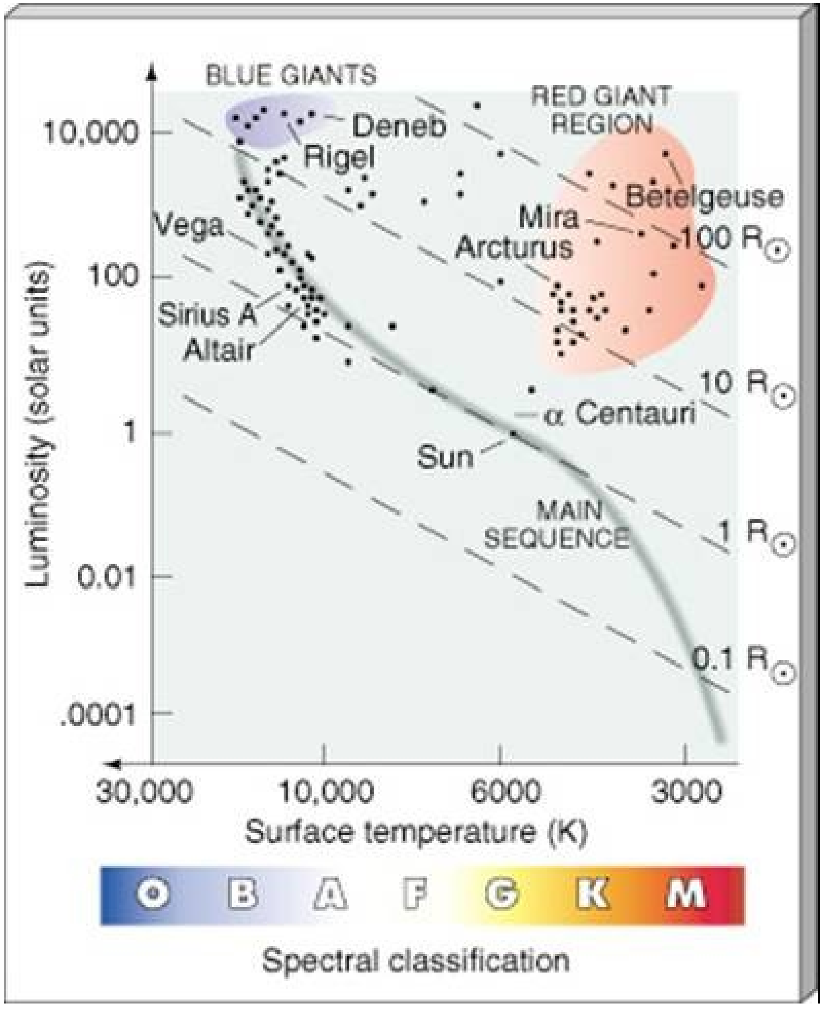
Stellar evolution

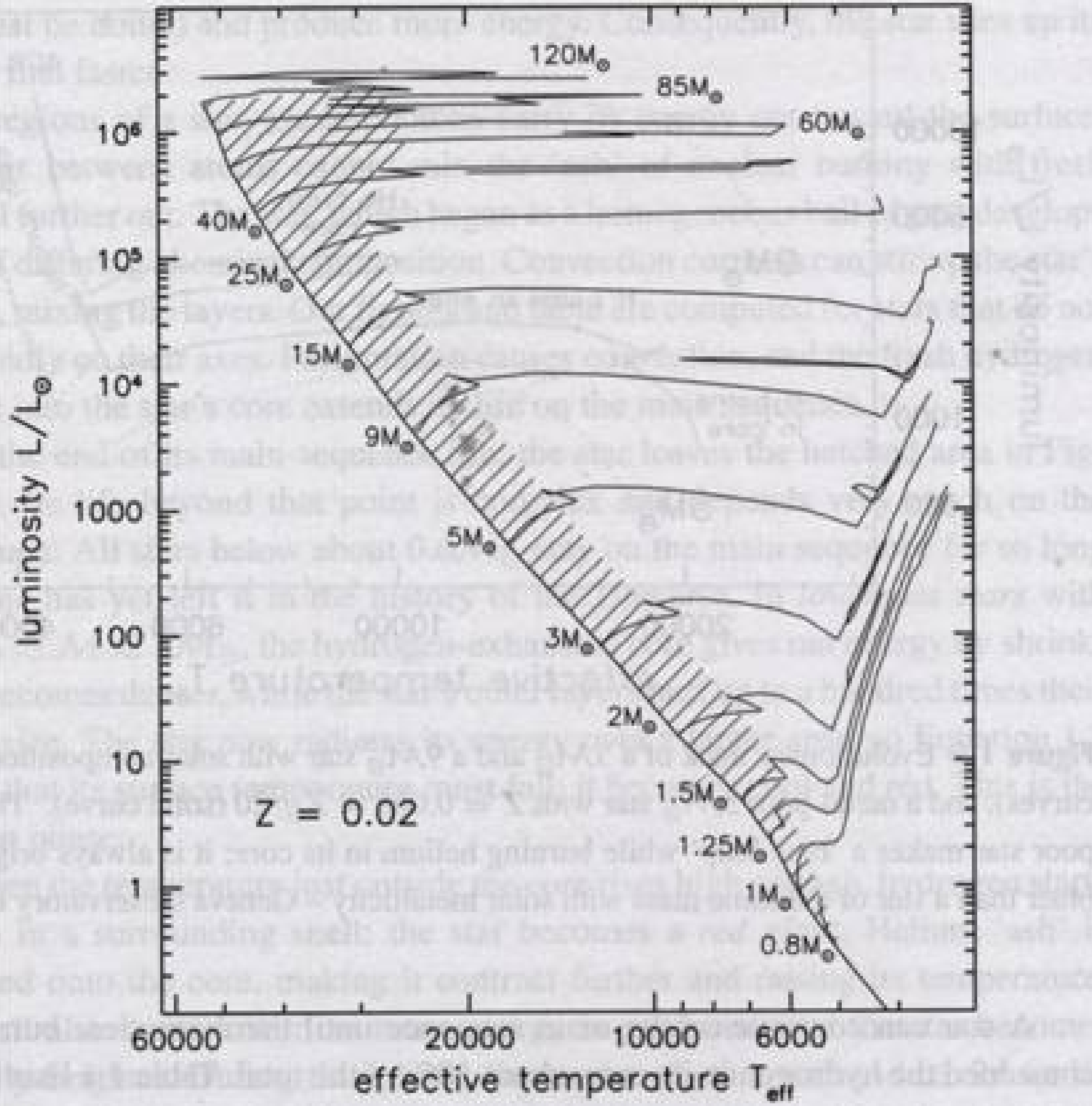
(a)As a star burns its H -> He the amount of H goes down
(b)The rate that the P-P cycle can make energy decreases
(c)Not enough pressure to hold up the outer layers
(d)So the core shrinks increasing the temperature
(e)That increases the P-P rate so the star stops shrinking
(f)Go to (a)

This will continue until all the hydrogen in the core is used up.

What is the Main Sequence

- It is where stars are burning hydrogen
- Most of a stars lifetime is spent on the MS
- Most of the stars we see are on the MS





.4 Luminosity and effective temperature during the main-sequence and later lives
with solar composition: hatched region shows where the star burns hydrogen in its
nly the main-sequence track is shown for the $0.8\mathcal{M}_\odot$ star – Geneva Observatory

4) end of MS life

$t \sim 10^{10}$ yrs

5)Post MS evolution

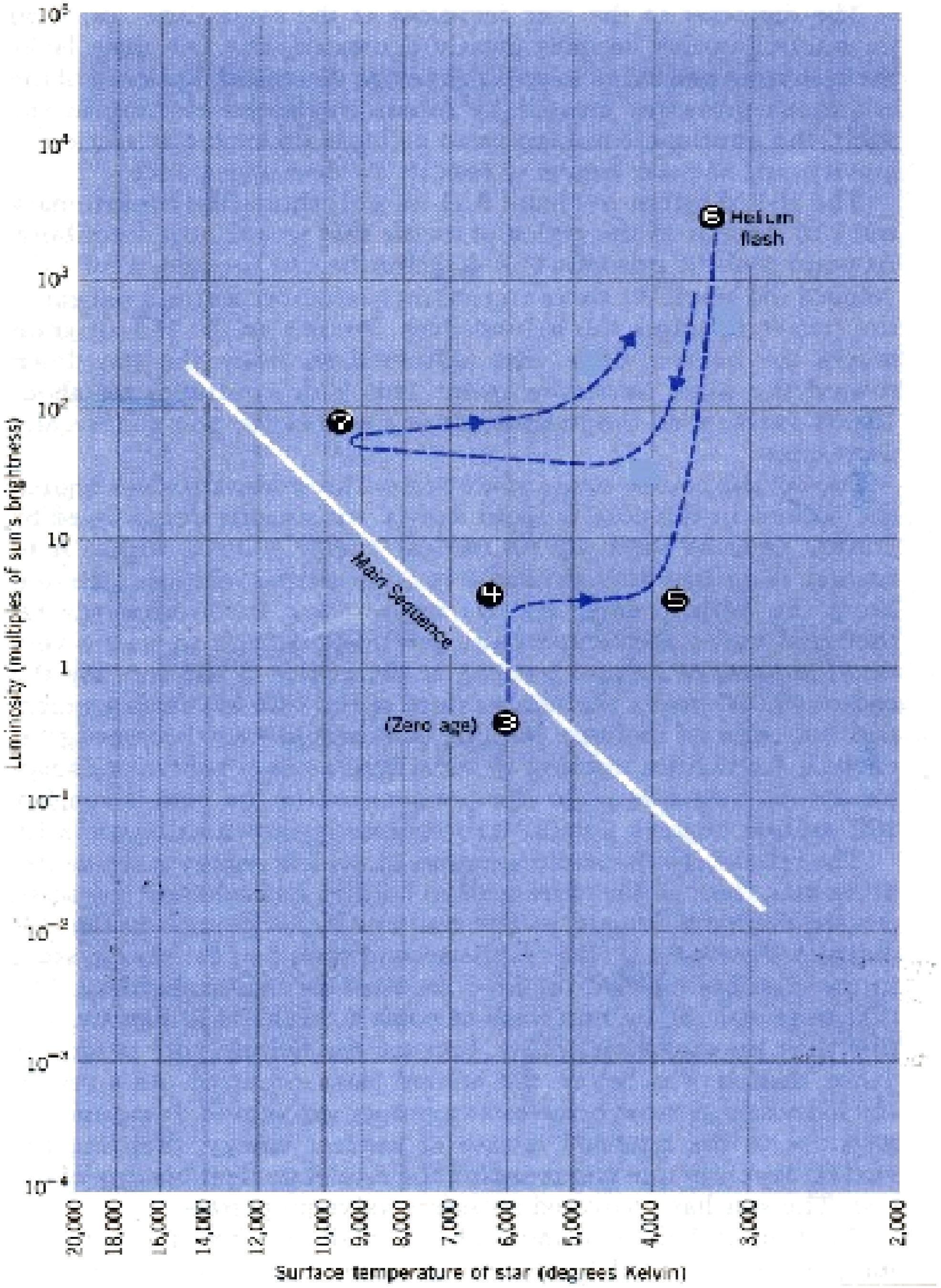
$t \sim 10^{9}$ yrs

6) Red Giant He flash

$t \sim 10^{8}$ yrs

7) He burning MS

$t \sim 10^{4}$ yrs



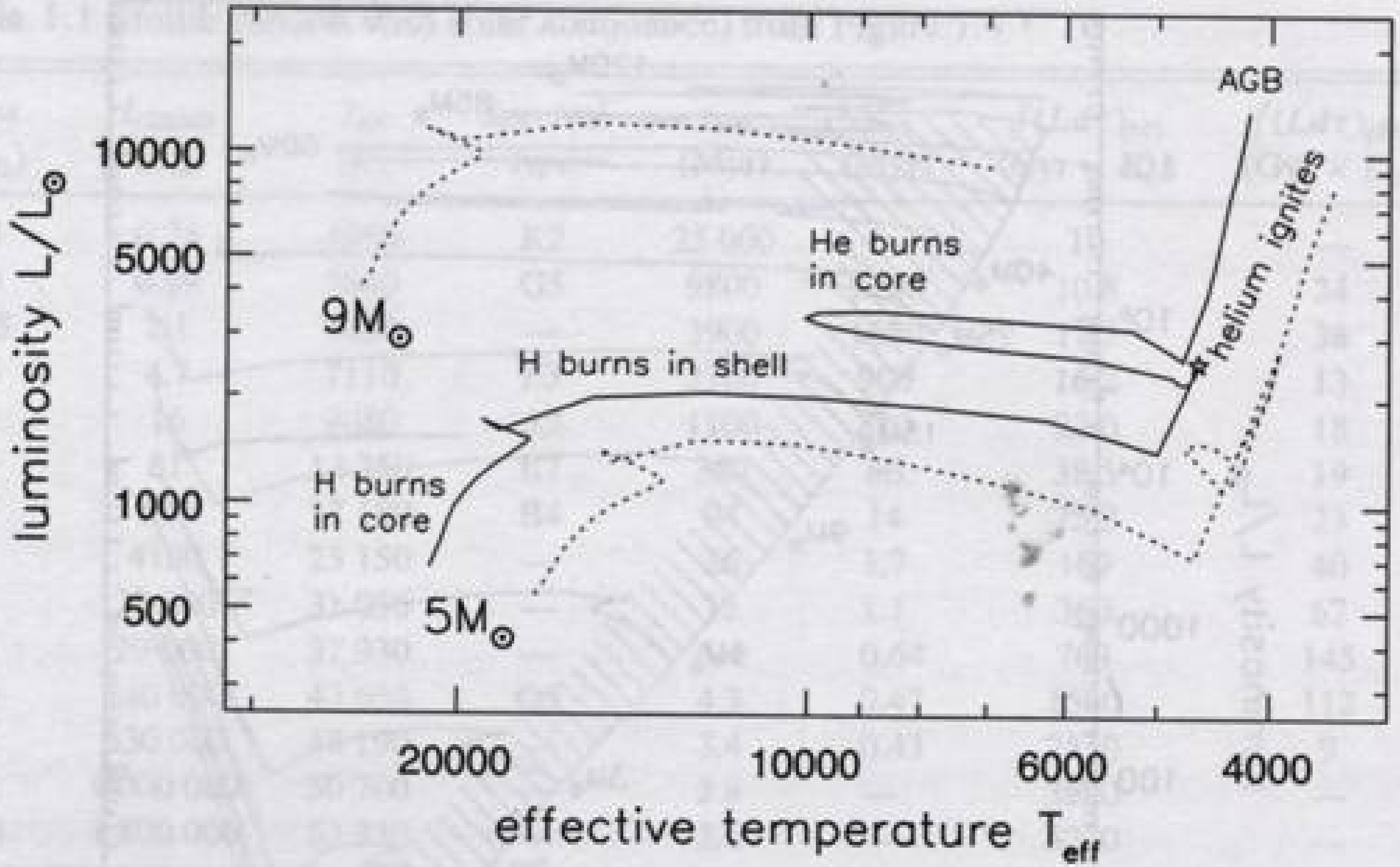
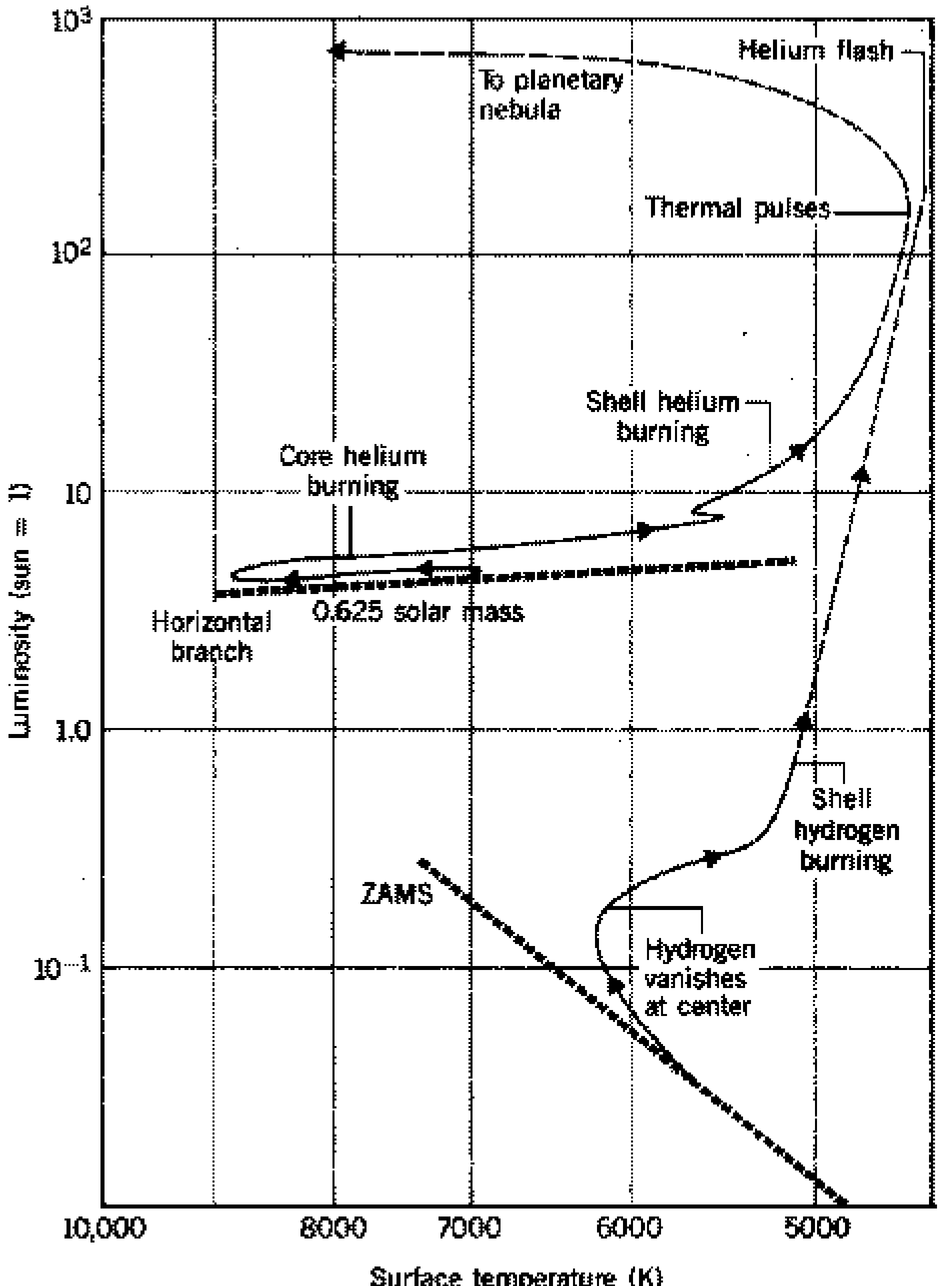


Figure 1.5 Evolutionary track of a $5\mathcal{M}_\odot$ and a $9\mathcal{M}_\odot$ star with solar composition (dotted curves), and a metal-poor $5\mathcal{M}_\odot$ star with $Z = 0.001 \approx Z_\odot/20$ (solid curve). The metal-poor star makes a 'blue loop' while burning helium in its core; it is always brighter and bluer than a star of the same mass with solar metallicity – Geneva Observatory tracks.

He Burning

- He burning only releases ~20% of the energy that H burning produces
- Lifetime in the He burning phase is only about $2x10^9$ yrs



Theoretical evolutionary track on an H – R diagram for a 0.7-solar-mass star off the main sequence.